GENETIC TREND, SELECTION INDEX, AND SELECTION RESPONSE IN AN ANGUS HERD

BY

SORNTHEP TUMWASORN

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TO MY PARENTS

CAPTAIN SOMBAT AND TONGLUEN

TO MY WIFE AND SONS

SOMYING, PATTARAWUTH, AND NATTAPOL

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Abstract of a Dissertation Presented to the Graduate School
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GENETIC TREND, SELECTION INDEX, AND SELECTION RESPONSE IN AN ANGUS HERD

By

Sornthep Tumwasorn

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A total of 1,246 records from Angus calves at the Brooksville Beef Cattle Research Station, Brooksville, Florida, collected during the years 1965 to 1979 were used to evaluate phenotypic and genetic trends and to develop selection indices utilizing the traits of birth weight (BW), weaning weight (WW), and preweaning average daily gain (PADG).

The solutions obtained from solving the fixed and mixed model equations were regressed on time to obtain trends for BW, WW, and PADG. Phenotypic trends for BW, WW, and PADG were .155, .955, and .006 kg per year, respectively. Genetic trends for these three traits based on sire contributions were .122, 1.207, and .006 kg per year, whereas the genetic trends based on dam contributions were .110, 1.323, and .003 kg, respectively.

Genetic and phenotypic parameters necessary for the construction of selection indices were estimated from the data. Both unrestricted indices and indices that restrict the increase of birth weight while allowing improvement in weaning weight were constructed independently for each sex and on a combined sex basis. These respective indices were found to be I = -3.7(BW - 25.6) + (WW - 190.1), I = -.004(BW - 23.7) + (WW - 177.9), and I = -2.24(BW - 24.7) + (WW - 184.5) based on data sets from male calves, female calves, and the combined sexes, respectively. The predicted responses to selection for weaning weight using the restricted indices were 73, 32, and 95% of that obtained using the unrestricted indices for the three data sets, respectively. Use of the indices developed from data from male calves and the combined sexes data were thus expected to be most effective in allowing increases in weaning weight while holding birth weight constant.

INTRODUCTION

The goals of beef cattle selection in the last 20 years have been based primarily on increasing weights and gains (Willham, 1979). In addition to single trait selection for individual growth traits, selection index procedures for multiple trait selection have been developed (Lindholm and Stonaker, 1957; Koch et al., 1974; and Nelsen and Kress, 1979). Due to the positive genetic correlations among all measures of sizes and growth, increases in postweaning weights and gains have resulted in an increase in birth weight which has led to deleterious increases in calving difficulties, and consequently, losses in production efficiency (Laster and Gregory, 1973). Indices that restrict increases in birth weight, while allowing other traits to increase, known as restricted indices, have been developed in Nebraska (Dickerson et al., 1974) and in Montana (Bourdon and Brinks, 1982). These restricted indices have as their objective increasing production efficiency through increases in postnatal growth while decreasing losses of profit due to calving difficulties that result from increased birth weights.

In Florida, selection of beef sires has often been based on weight at 20 months and postweaning gain (Koger et al., 1975). Continuous selection based on these criteria has the potential for eventual losses due to difficult births. Thus, the development of indices for use in selection for growth traits while restricting increases in birth weight that are appropriate for Florida is of considerable importance.

It is also important to be able to evaluate the results of a selection program after selection has been practiced in a herd over a number of years. Phenotypic and genetic trends are measures of phenotypic and genetic changes per year. However, only few such evaluations have been conducted using data from Florida beef herds (Stewart, 1974; Beltran, 1978). The knowledge of phenotypic and genetic trends together with the ability to develop selection indices are therefore important to beef cattle breeders. Information obtained will enable breeders to draw general conclusions about the results of selection in the past, and at the same time be able to determine selection criteria for the future breeding and selection programs.

This study has as its two main objectives, (1) to evaluate phenotypic and genetic trends in birth weight, weaning weight, and preweaning average daily gain in an Angus herd, and (2) to develop selection indices, especially indices that restrict increases in birth weight while allowing increases in weaning weight.

In this study, the evaluation of genetic and phenotypic trends and the development of selection indices will be presented as separate chapters.

LITERATURE REVIEW

Genetic Parameters in Beef Cattle

Parameter estimates from data sets vary depending on the model used. This has been particularly true in estimating genetic parameters of beef cattle. Important parameters in beef cattle pertain to the estimation of the effects of sires and dams, heritability, and genetic, phenotypic, and environmental correlations. Henderson's method 3, for variance and covariance component estimation, has been frequently used due to the ease of computation. Many additional methods of variance and covariance component estimation have become available since the introduction of the maximum likelihood procedure by Hartley and Rao (1967). A review of estimates of variance and covariance components will be discussed separately.

Birth Weight

Estimates of the heritability of birth weight have varied from -.10 to 1.1 with a mean value of .40. Estimates below .25 were found in Montana (Knapp and Nordskog, 1946), California (Rollins and Guillbert, 1954), South Dakota (Minyard and Dinkel, 1960), and Nebraska (Swiger, 1961). Medium estimates, ranging between .25 and .55, were reported by Knapp and Clark (1950) in Nebraska, Dawson et al., (1954) in Louisiana, Vesely and Robison (1971) in North Carolina, and Koger et al., (1975) in Florida. Heritability estimates above .55 are regarded in general as high and were reported by many authors (Rollins and Guillbert, 1954; Koch et al., 1973; Koger et al., 1975). The differences among the estimates were due largely to the methods employed for estimation of variance component (Falconer, 1981), different numbers of observations, and differences among the models fitted (Pirchner, 1983).

Weaning Weight

Estimates of heritability for weaning weight were classified in the same manner as those for birth weight. Heritability estimates less than .25 for weaning weight were reported by Knapp and Nordskog (1946) and Koch and Clark (1955) in Montana, Minyard and Dinkel (1960) in South Dakota, and Koger et al. (1975) in Florida. Medium estimates, between .25 and .55, were found by many authors (Gregory et al., 1950; Minyard and Dinkel, 1960; Vesely and Robison, 1971; Francoise et al., 1973; Koger et al., 1975). Among high estimates, Gregory et al. (1950) reported a value of 1.1 using the paternal half-sib method. Other estimates have ranged between .63 and .80 (Carter and Kincaid, 1959; Dunn et al., 1973).

Preweaning Average Daily Gain

Estimates of heritability for preweaning average daily gain ranged from .18 to .96 (Warwick and Cartwright, 1955; Shelby et al., 1955; Brown and Maximo, 1963; Marlowe and Vogt, 1964; Hallman, 1966; Chapman et al., 1972). Estimates of heritability for preweaning average daily gain has seldom been reported.

Correlations among Preweaning Weights and Gain

Correlation between traits can be measured phenotypically (phenotypic correlation) and genetically (genetic correlation). Phenotypic correlation is defined as the correlation between traits that can be observed or measured. The genetic correlation is the correlation between two characters that is caused by the effects of the same gene(s) which is called pleiotropy. Correlations between traits are of interest of many reasons. One such interest is in connection with the changes brought about by selection in one character that result in simultaneous changes in other characters.

Genetic correlations between birth weight and weaning weight have been found to be medium to high, ranging from .42 to .94. Medium estimates of .42 to .55 were reported by Brinks et al. (1962). Estimates above .65 were obtained by Shelby et al. (1963), Dunn et al. (1973), and Vesely and Robison (1971). Phenotypic correlations between birth and weaning weights have generally been found to be low to medium, ranging from .12 (Koch and Clark, 1955) to .43 (Kress and Burfening, 1972). Other estimates around .35 were obtained by Brinks et al. (1962), Shelby et al. (1963), and Koch et al. (1973).

Genetic correlations between birth weight and preweaning average daily gain have ranged from .10 (Koch et al., 1973) to a medium value of .50 (Chapman et al., 1972). An average value of about .30 has been found by many researchers (Swiger et al., 1965; Shelby et al., 1963; Pahnish et al., 1963). In general, phenotypic correlations between birth weight and preweaning average daily gain have been low. An average estimate of .20 has been reported by many authors (Swiger et al., 1965; Shelby et al., 1963; and Koch et al., 1973).

Genetic and phenotypic correlations between weaning weight and preweaning average daily gain have generally been high, ranging from .77 to .98 (Shelby et al., 1963; Pahnish et al., 1964; Koch et al., 1973).

Phenotypic and Genetic Trends

The phenotypic trend for a trait can be defined as the change in that trait per unit of time. The change per unit of time that is caused by genetic effects is called genetic trend. Estimation of genetic trend is a method to evaluate the genetic progress attained by selection. The difference between the phenotypic trend and the genetic trend of a trait is due to effects caused by feeding, management, and other conditions which are considered to be environmental. Environmental improvements generally result in rapid changes in production, but they usually require a considerable investment, which may need to be repeated each generation. Genetic improvement, on the other hand, can be considered permanent once achieved and requires no further investment of effort to maintain it under most circumstances. The separation and evaluation of genetic and environmental changes are, therefore, important in making proper decisions regarding future selection criteria and in evaluating the effects of previous selection programs. Least squares and mixed model methods have usually been employed in estimating phenotypic and environmental changes (Henderson, 1973, Kwakalor et al., 1976, Quaas and Pollak, 1980). An evaluation of methods used in estimating trends was reported by Brown (1976). Methods of evaluating genetic trend, however, began to change after 1975, when new methods were introduced through the use of

Henderson's mixed models.

Trends for Birth Weight

Discussions of genetic and environmental trends for birth weight have been made since 1960 by various authors. Regression of birth weight on year of calf birth was estimated to be around .14 kg per year (Petty and Cartwright, 1966; Dickerson, 1969; Newman et al., 1973; Koch et al., 1974).

Trends for Weaning Weight

Flower et al. (1964) found a positive genetic trend and a negative environmental trend for weaning weight in an 8-year study with Hereford cattle. In general, most reports of genetic trends for weaning weight have been similar and have shown positive values (Chapman et al., 1969; Newman et al., 1973; Koch et al., 1974; Beltran, 1978; Luesakul, 1983). It has been observed that the use of mixed model equations (MME), which contain both sire and dam components and their relationships, give reliable results for trend analyses (Wilson, 1984 and Skaar, 1985).

Trends for Preweaning Average Daily Gain

Trend analysis for preweaning average daily gain (PADG) seldom have been conducted, since that trait is a function of birth weight and weaning weight. Most reports showed a positive genetic trend for PADG (Luesakul, 1983; Tumwasorn et al., 1986). Trend for PADG were in agreement with those for weaning weight, due to the high genetic correlation between these two traits.

Variance and Covariance Components

Variance and covariance components measure the sources of variation among and within individuals that belong to the same or different subgroups of population. It is easy to estimate these components when there are equal numbers of individuals within groups, since the data structure is said to be balanced. Searle (1979) documented that variance components calculated from balanced data had several desirable known properties;

(1) they are unbiased,

(2) under normality, sampling variances are available,

(3) they are easy to compute,

(4) they have minimum variance among all quadratic unbiased estimators, and

(5) under normality, they have minimum variance among all unbiased estimators.

Data with unequal numbers of observations in the subclasses, including perhaps some that contain no observations at all (empty subclasses or empty cells), are called unbalanced data. In contrast to balanced data, the analysis of unbalanced data is much more complicated. The methods used from 1940 to 1970 were based on equating mean squares to their expected values. Eisenhart (1947) and Schultz (1955) introduced rules for estimating variance components from a random model with balanced data. The procedure of equating mean squares to their expectations was first proposed in early papers of Daniels (1939) and Winsor and Clarke (1940) for balanced data. Graybill and coworkers (Graybill, 1954; Graybill and Wortham, 1956; and Graybill and Hultqkuist, 1961) derived useful minimum variance properties for many different models associated with balanced data.

The topic of unbalanced data was first introduced by Henderson (1953), whose paper dealt with three methods of estimating variance components. The methods proposed by Henderson used the same concept as that for analysis of variance in the balanced case, namely equating quadratic forms of observations (rather than just sums of squares) to their expected values. However, properties of the estimates, as in the unbalanced case, were mostly unknown, in spite of their ease of computation. Henderson's method 1 dealt with the random effects model, whereas methods 2 and 3 dealt with mixed models (models containing both fixed and random effects). Since method 1 was not appropriate for mixed models, method 2 was designed to correct that deficiency by adjusting the variance components estimated for the fixed effects. Method 2 is not applicable, however, when the mixed model contains interactions between fixed and random effects (Searle, 1968). Method 3 is applicable to both random and mixed models, even when interactions exist between fixed and random effects. Henderson's method 3 includes a procedure for choosing a sufficient number of reductions in sums of squares due to fitting submodels so that their expected values of differences between the reductions are free from any fixed effects. Method 3 is preferable over method 2. Method 3, however, does not produce unique estimates, since there can be more equations to solve than there are variance components to estimate.

Methods of estimation of covariance have the same problems as those for variance component estimation. However, estimation of covariance has additional complications. Covariance component estimates have largely been calculated by Henderson's method 3 due to its advantage in mixed model equations. This advantage is that the estimate is unaffected by fixed effects. Searle (1971) documented that Henderson's method 3 was a preferred method for covariance component estimation. However, since the introduction of many methods for variance component estimation, comparisons of variance and covariance estimates from different methods are becoming more available. Examples of comparisons of estimates from various methods have been reported by many authors (Henderson and Quaas, 1977; Quaas and Bolgiano, 1979; Wilkes, 1983; and Swallow and Monahan, 1984).

The use of variance and covariance components in animal breeding and genetics was reviewed by Freeman (1979). In his review, Freeman mentioned that the calculation of components of variance was probably initiated using simple between and within one-way analyses of variance. The components of variance were then obtained as between and within groups, and they were used as a method to estimate the repeatability of the trait (Lush and Jones, 1923) using a procedure first outlined by Fisher (1918). It was pointed out, however, that the method they proposed was not the same as that documented earlier by Wright (1921), in his work on "Correlation and Causation", in which path coefficients were used. Nested designs, such as sires within groups, litters within sires, and individuals within litters, were introduced by Dickerson (1942) and Hazel et al. (1943) to estimate variance components.

Heritability is defined as the ratio of the variance component caused by genetic effects to the total variation of the trait. Heritability has been stated to be the most useful genetic parameter, since expected genetic gain due to selection is based on heritability. In the same manner, to predict the response from selection for many traits at one time, the variances and covariances among these traits must be known (Hazel, 1943; Henderson, 1963, 1973).

In real situations in animal breeding, unknown means, variances and covariances of observed records, unequal information on the candidates for selection, and highly nonorthogonal data are common. This has created serious problems in determining the most genetically superior animals. Various strategies have been derived to deal with these problems. Hazel's selection index and the methods suggested by Lush (1931, 1933) were in the class of best linear predictors (BLP) because, in both cases, it was assumed that means and variance were known without error. If only the variance is known and unknown mean and has to be estimated from the population being studied, this procedure is no longer BLP. Henderson (1973, 1974) introduced a method of selection to be used only when the variance was known, called best linear unbiased prediction (BLUP). The BLUP procedure has been used extensively in dairy cattle and is being applied increasingly to beef cattle, swine, and poultry. When both mean and variance are unknown, Henderson (1985) documented ways to cope with this situation. Gianola et al. (1986) derived a new method to use the Henderson approach (Henderson, 1985) which dealt with selection procedures when both variance and mean are unknown. The properties of the procedure proposed by Gianola and coworkers are now being discussed.

Selection and Its Response in Beef Cattle

Weight and measurements at early stages of life have been considered to be the most appropriate criteria for selection for size and growth at later stages (Lindholm and Stonaker, 1957; Nelsen and

Kress, 1979). Female selection and culling criteria have been based primarily on reproductive failure in commercial beef herds, while more emphasis has been placed on growth traits such as weaning weight and yearling weight in purebred beef herds. It is well accepted that selection based on sizes and growth and reproductive performance will increase the profit of the cattle business as a whole (Koger, 1968).

There have been problems, however, concerning response to selection under the criteria mentioned above in beef cattle. This is caused by the high genetic correlation between weight at birth and those at later stages of life. A negative correlated response to selection for growth rate in beef cattle has been the increase in calving difficulty associated with increased birth weight. When heavier sires were introduced in a herd with smaller-sized cows, calving difficiculty increased tremendously, especially when large sire breeds were used on small cows and heifers of the English breeds (Koger et al., 1975). The increased death loss associated with calving difficulty reduces efficiency of production as measured by calf weaning weight per cow exposed to breeding to a great extent (Laster et al., 1973). Use of selection index that prevents increases in birth weight while allowing increases in postnatal gains has been suggested to help prevent further increases in dystocia and its associatged losses. Dickerson et al. (1974) predicted the response to selectgion using a selection index restricted on birth weight, but which allowed increased in yearling weight. It was reported by Dickerson and coworkers that a selection index restricted on birth weight would reduce rates of correlated response in increased birth weight, as compared solely to selection on yearling weight, by 55 percent and in mature weight by

25%, while retaining 90% of the potential improvement in yearling weight.

Response to Single Trait Selection

Flower et al. (1964) predicted the selection response in range Hereford cattle in Montana and reported that the average genetic changes per year for birth weight and weaning weight were .43 and 2.07 kg, repectively. Chapman et al. (1972) compared criteria for selecting introduced beef sires that were selected for one of the following traits; high daily rate of postweaning gain, high weaning weight, high yearling type score, or average levels of performance in all three traits. They reported that the progeny of bulls selected for high postweaning gain and those of bulls selected for high weaning weight were similar in postweaning average daily gain and superior to those of bulls selected for type score and average performance values. The steers from bulls selected on weaning weight were slightly heavier ($P<.05$) than those from the other herds for both postweaning average daily gain and final weight per day of age.

Koch et al. (1974) studied selection response in three lines of Hereford cattle selected for weaning weight, yearling weight, and an index of yearling weight and muscling score. They concluded that the response to selection for weaning weight was low as compared to selection for yearling weight and the index of yearling weight and muscling score.

Changes occurring in cattle as a consequence of selection for growth rate in a stressful environment were reported by Frisch (1981). The sources of stress were low plane of nutrition, high ambient temperature and infection with bovine infectious keratoconjunctivitis. Frisch concluded that the selected line was more heat tolerant, having a lower maintenance requirement and a greater resistance to bovine infectious keratoconjunctivitis and, as a consequence, always had higher growth rates. Frisch also stated that selection had not increased the components associated with growth potential, but the improvement in growth rate was achieved entirely through increased resistance to environmental stresses which affected growth rate.

Response to Multiple Traits Selection

Lindholm and Stonaker (1957) developed a selection index based on weaning weight, daily gain, days to finish, and feed efficiency. In comparing different indices, they concluded that weaning weight alone was an accurate basis for selecting for increased net income in Hereford cattle. They stated that an index containing weaning weight and preweaning daily gain was found, in terms of correlation between the index and aggregated genetic values, to be as good as indices containing weaning weight and postweaning weight. Selection responses using different indices were reported by Koch et al. (1974) and compared to direct response to selection on an individual trait. They found that selection based on an index of yearling weight and muscling score was not as good as the response due to direct selection on yearling weight when considering the correlation between index and aggregate genetic values as the measure of usefulness of the index.

When models used in the construction of selection indices are not appropriate, the estimates of variance and covariance components obtained will be biased. The introduction of mixed model equation

(MME) methodology to the estimation of variance and covariance components and the prediction of response using best linear unbiased prediction (BLUP) by Henderson (1975) have given us better estimates of variance and covariance components. The use of mixed model equation methodology in selection procedures has rapidly increased the accuracy of prediction of superior animals (Van Vleck et al., 1977).

Willham (1979) suggested using mature size and rate of maturity as criteria for selecting beef sires. Unfortunately, a comparison of responses expected from utilizing alternative selection criteria, such as mature size and rate of maturity, has not been made. Butts (1986) suggested that selection for growth parameters, i.e, rate of maturity under different feeding and environmental conditions would not give optimum response in breeds of varying mature size. Therefore, Butts (1986) stated that fitting appropriate genotypes to appropriate environments should be a topic in beef cattle production under subtropical conditions.

Relative Economic Values for Multiple Traits Selection

Genetic improvement in traits of economic importance should result in greater net income, both to the feeder and the cow-calf producer. Most of the discussion of economic values will be restricted to preweaning traits. Lindholm and Stonaker (1957) constructed an index based on 118 Hereford steers and using weaning weight, gain from birth to weaning, weaning grade, postweaning gain, postweaning feed efficiency, and slaughter grade as criteria for selection. Relative economic values were obtained by regressing net income per calf on the specific independent traits used in the index. Variable costs in this study were assumed to vary directly with feed intake and were proportional to the weight of the dam. The economic values of weaning weight and gain from birth to weaning were found to be $.32 and $15.82 per kilogram. It should be noticed, however, that a very high calf crop of 88% was used to estimate the cost per calf produced over a 12 year period (1940-1951).

Lehman et al. (1961) developed a selection index based on growth and type score for weaning beef calves from Angus, Hereford, and Shorthorn herds in Virginia. The economic value of preweaning average daily gain was calculated according to the following procedure: (1) the value of a weaned calf was found to be $180.87 by multiplying the value per kilogram (99 cents) by the average weaning weight (183.00 kg) of all calves used; (2) the mean daily growth rate of a calf, .75 kg per day, was computed by subtracting the average birth weight (31.00 kg) from the average weaning weight (183.00 kg) and dividing by the average age at weaning (203 days); (3) the mean daily growth rate was divided into the value per weaned calf to yield an estimate of $119.97 as the value of a kilogram of daily gain (rounded to $120.00). The economic values expressed as partial regression coefficients for preweaning average daily gain and type score on cost per calf were found to be $23.74 and $.75 per kilogram. Suggestions made by Lehmann and coworkers were: (1) the economic values of bulls and heifers at weaning were usually different, (2) the parameters computed might be different in the different breeds and sexes, and (3) the indices and discussion pertaining to performance testing should be compared with indices computed using field data.

During the years 1960 to 1970, more reports on selection index in beef and dairy cattle became available, especially reports on estimates of economic values in beef cattle. Estimation of the cost of calf production per cow was discussed thoroughly by Koger (1968). Cow maintenance costs were positively correlated with cow size because of feed requirements. Koger mentioned two items that offset the increased cost associated with large size. These factors were the heavier weight to sell when the cow was culled and the fact that some costs of production that were determined on a per head basis were comparatively less since larger beef cows produced more per head. It was also pointed out that, because of these two factors, the cost per pound of calf produced was approximately constant over a rather wide range of cow size.

Conventional selection indices for birth and weaning traits in beef cattle were reported by Vesely and Robison (1971). The net economic return of weaning weight was derived under the following assumptions. The gross economic value of weaning weight, \$.55 per kg, was obtained from an average price of steer and heifer calves. The average annual cow cost was taken arbitrarily at \$50.00. It was agreed that the annual cow cost would fluctuate considerably because it depended on so many economic factors that vary greatly from farm to farm. It was assumed that the cost per cow per kilogram of calf weaned was constant regardless of the calf's weight, and the net economic value of weaning weight was determined to be \$.31 per kg. Index involving birth weight and weaning weight was reported to be $I = BW + .9(WW)$.

Dickerson et al. (1974) reported very comprehensive selection criteria for efficient beef production. They analyzed data from Hereford, Angus, and Shorthorn herds raised at the Fort Robinson Experiment Station, Nebraska. Selection indices for efficiency were developed using four different definitions of efficiency. Efficiency was defined as value of boneless retail cuts, adjusted for marbling score, less feed and time variable costs, from 200 days of age or from 182-kg live weight to a 410-kg slaughter weight, or from 200 days to constant age at slaughter. The most critical finding was that when the net effects of calf mortality, reproduction, and cow size were included in a definition of efficiency, expected improvement was increased 6 to 7% by adding selection for smaller birth weight to that for heavier yearling weight. Two weaknesses in the foregoing evaluation were stated by the authors. First, the selection for heavier yearling weight had adverse correlated effects on percent calf crop. This was a consequence of higher calf losses (Laster and Gregory, 1973) and delayed rebreeding (Laster et al., 1973). The second weakness was that cow herd overhead costs increased as a result of increased cow size and milk production. The increase in birth weight of calves could be minimized by selection for smaller birth weight in conjunction with heavier yearling weight. Relative economic values estimated in the Dickerson article were based on reports from the United States Meat Animal Research Center in 1973 and Laster et al. (1973) that indicated that increasing birth weight by one kg would reduce calf crop by .27% and increase calving difficulty by 2.4%. In herds averaging 80% calf crop raised with annual costs of $125.00 per cow, the cost per calf was $156.25 (125/.80). Reducing calf crop by 1.05% changed cow cost per calf to $158.33 (125/.7895), an increase of $2.07 in calf cost per kilogram increase in birth weight.

Koch et al. (1974) reported a selection response in beef cattle based on weaning and yearling weights during the years 1960 to 1970 with no details about estimating relative economic value. Selection indices were developed with assumed relative economic values.

In Canada, Morris and Wilton (1975) studied the influence of mature cow weight on economic efficiency in beef cattle production using linear programming. They mentioned that although it was common in animal breeding to derive economic values from costs and returns at the farm level, it was not clear that the values obtained would extend to regional or national levels. In the Morris and Wilton study, economic values of weaning weight, mature cow weight, and average daily gain in the feedlot were considered to be relatively the same. Melton et al. (1979) proposed a method for estimating economic value for selection indices using a profit function. The profit function was maximized by equating the partial derivatives of the function with respect to each input to zero and simultaneously solving the resulting system of first-order equations for optimal levels of the variables. Thompson (1980) commented on the estimation of economic values for selection indices. He indicated that the economic values proposed by Melton and coworkers had limitations in cases when observed values of independent variables used in the index were extreme in either directions.

STUDY I:
SELECTION INDEX AND PREDICTED RESPONSE

Introduction

To increase the productivity of beef cattle, selection should be made on several characters simultaneously. One method of multiple selection utilizes index procedures using several measurements of growth such as birth weight, weaning weight, and yearling weight. Unfortunately, many of the selection indices that were developed ignored potential deleterious effects of correlated responses of increased birth and mature weights (Warwick and Legates, 1979, Aaron et al., 1985). In beef cattle, it has been found that the increased death loss associated with calving difficulty reduces efficiency of production as measured by calf weaning weight per cow exposed to breeding to a great extent (Laster et al., 1973). Restricted selection indices that attempt to minimize the deleterious effects of correlated responses in beef cattle have been developed in the central and northern parts of the United States by Dickerson et al. (1974) in Nebraska and Bourdon and Brinks (1982) using data from Montana. The theoretical basis of these restricted selection indices was reported by Dickerson et al. (1974) and Mendoza and Slanger (1985). However, selection indices, especially restricted ones, have not been developed using data from the southern region.

This study has as its main objective the development of selection indices based on birth weight and weaning weight that will restrict increases in birth weight.

Materials and Methods

Source of Data

The data for this study were collected over a 15-year period (1965 to 1979) from the Angus herd at the USDA Beef Cattle Research Station (Subtropical Agricultural Research Station), Brooksville, Florida. The data consisted of birth weight, weaning weight, and preweaning average daily gain. The Angus herd was established at Brooksville in 1950 from two groups of half-sisters brought from the Everglades Experiment Station, Belle Glade, Florida. Subsequent introductions were from the USDA herd located at Front Royal, Virginia, private herds located in the Front Royal area, and a few private herds located in North Florida (Stewart, 1974).

Following weaning all calves were maintained on pasture with some supplemental feeding. Bull calves were supplemented with about 4.5 kg of a feed with a high total digestible nutrient content daily until 18 months of age. Replacement bulls were selected based on 18 month weight and postweaning gain with some attention given to soundness and productivity of their dam. Heifer calves received only limited supplementation on pasture until 18 months of age. At 18 months of age, approximately 15% of the heifers were culled due to poor rate of gain or unsoundness. The remaining 85% were exposed to bulls for about 60 days at about 2 years of age and delivered their first calves at 3 years of age. Females failing to conceive were culled. Approximately 5-15% of the cow herd was culled each year because of low production, depending on the number of pregnant cows and heifers, making the total proportion of females culled each year about 25%.

Data Structure and Description

The data set consisted of 1,246 records of birth weight, weaning weight, and preweaning average daily gain. The distribution of data is presented in table 1 by year of calf birth, number of sires used, and sex of calf. There were 96 sires used during the years 1965 to 1979 which sired 675 male and 571 female offspring. Arithmetic means and standard deviations for the three preweaning growth traits are shown in tables 2, 3, and 4. The calves in this herd averaged 24.7, 184.5, and .699 kg for birth weight, weaning weight, and preweaning average daily gain, respectively.

Model Description and Statistical Analyses

Variance and covariance components for birth weight, weaning weight, and preweaning average daily gain were estimated to develop the selection indices. The parameter estimates from this data set will be compared with literature averages. In addition, genetic and phenotypic parameters and their approximate standard errors will be estimated.

Estimation of variance and covariance components

Phenotypic and genetic variance and covariance components were estimated from paternal half-sib analyses using the mathematical model:

TABLE 1. NUMBER OF OBSERVATIONS BY YEAR OF CALF BIRTH, SIRE, AND SEX OF CALF DURING THE YEARS 1965 TO 1979

Year of calf birth	Number of sires used	Number of male calves	Number of female calves	Total calves
1965	7	28	19	47
1966	6	36	34	70
1967	6	34	29	63
1968	6	33	20	53
1969	6	50	45	95
1970	6	54	47	101
1971	8	58	40	98
1972	8	50	51	101
1973	7	57	37	94
1974	12	45	46	91
1975	9	63	43	106
1976	12	44	37	81
1977	9	51	44	95
1978	6	41	47	88
1979	6	31	32	63
Overall		675	571	1246

TABLE 2. ARITHMETIC MEANS AND STANDARD DEVIATIONS OF BIRTH WEIGHT BY SEX OF CALF AND SEXES COMBINED

Year of calf birth	Male calves		Female calves		Sexes combined	
	Mean (kg)	SD[a]	Mean (kg)	SD	Mean (kg)	SD
1965	25.98	4.58	23.19	4.31	24.85	4.64
1966	26.96	3.05	23.95	2.88	25.50	3.32
1967	24.80	3.86	23.47	2.96	24.19	3.51
1968	27.34	4.43	25.83	4.37	26.77	4.42
1969	25.86	4.07	23.06	4.50	24.53	4.48
1970	24.88	3.14	22.92	2.23	23.97	2.91
1971	25.18	2.90	22.48	2.76	24.07	3.13
1972	24.11	2.23	22.56	2.59	23.33	2.53
1973	23.53	3.00	22.16	2.81	22.99	2.99
1974	25.65	3.95	23.84	3.23	24.73	3.70
1975	26.92	3.68	24.57	3.52	25.96	3.78
1976	24.87	3.28	23.47	4.54	24.23	3.94
1977	26.72	3.86	24.48	4.00	25.68	4.07
1978	28.73	4.37	26.41	3.56	27.49	4.10
1979	23.03	3.44	23.11	3.93	23.07	3.67
Average	25.61	3.82	23.67	3.63	24.72	3.85

[a] Standard deviation.

TABLE 3. ARITHMETIC MEANS AND STANDARD DEVIATIONS OF WEANING WEIGHT BY SEX OF CALF AND SEXES COMBINED

Year of calf birth	Male calves		Female calves		Sexes combined	
	Mean (kg)	SD[a]	Mean (kg)	SD	Mean (kg)	SD
1965	192.05	18.94	181.11	22.73	187.63	21.03
1966	196.13	20.63	189.19	18.20	192.76	19.66
1967	172.28	17.58	174.36	18.04	173.24	17.68
1968	198.18	18.35	184.08	25.30	192.86	22.11
1969	190.28	26.03	169.80	25.97	180.58	27.83
1970	184.71	20.55	163.83	15.84	174.99	21.18
1971	186.54	20.56	165.98	19.26	178.15	22.38
1972	186.44	18.14	169.75	17.27	178.01	19.51
1973	189.89	22.60	180.27	22.23	186.10	22.83
1974	182.98	40.33	168.38	27.91	175.60	35.19
1975	182.62	26.02	174.05	18.03	179.14	23.40
1976	202.14	32.62	175.49	24.40	189.96	31.91
1977	195.64	18.78	194.62	17.74	195.16	18.22
1978	204.02	23.01	189.81	22.38	196.43	24.05
1979	194.28	22.01	201.44	19.05	197.91	20.71
Average	190.06	25.08	177.88	23.57	184.48	25.13

[a] Standard deviation.

TABLE 4. ARITHMETIC MEANS AND STANDARD DEVIATIONS OF PREWEANING AVERAGE DAILY GAIN BY SEX OF CALF AND SEXES COMBINED

Year of calf birth	Male calves		Female calves		Sexes combined	
	Mean (kg)	SD[a]	Mean (kg)	SD	Mean (kg)	SD
1965	.731	.079	.686	.071	.713	.078
1966	.714	.076	.685	.070	.699	.074
1967	.647	.077	.660	.077	.653	.077
1968	.773	.063	.702	.071	.746	.075
1969	.725	.097	.652	.097	.690	.103
1970	.713	.079	.618	.057	.668	.084
1971	.771	.088	.683	.066	.735	.091
1972	.692	.074	.649	.073	.670	.077
1973	.716	.067	.672	.078	.698	.074
1974	.732	.127	.672	.075	.701	.107
1975	.661	.109	.615	.073	.642	.098
1976	.773	.087	.652	.066	.717	.099
1977	.724	.073	.692	.052	.709	.066
1978	.771	.074	.718	.066	.743	.074
1979	.748	.089	.766	.077	.757	.083
Average	.724	.093	.671	.080	.699	.091

[a] Standard deviation.

$$Y_{ijkl} = Mu_i + S_{ij} + F_{ik} + e_{ijkl} \qquad \text{..................} \ 1$$

where Y_{ijkl} = the l^{th} observation on trait i with the k^{th} set of fixed effects, with sire j, and $i = 1, 2, 3$ for birth weight, weaning weight, and preweaning average daily gain,

Mu_i = overall mean of the i^{th} trait,

S_{ij} = effect of the j^{th} sire on the i^{th} trait. S_i was assumed to be NID (0, $\sigma^2_{S(i)}$), where

$_{S(1)}$ is the sire variance for birth weight,

$_{S(2)}$ is the sire variance for weaning weight, and

$_{S(3)}$ is the sire variance for preweaning average daily gain, and $COV_{S(i,i')}$ is the sire covariance between trait i and i',

F_{ik} = the k^{th} set of fixed effects on the i^{th} trait. This set of fixed effects contain year of calf birth, sex of calf, and age of dam. For weaning weight and preweaning average daily gain, the F_{ik} contain the age of the calf as a covariate, and

e_{ijkl} = the residual remaining after fitting other effects associated with the record of the l^{th} calf, which was assumed to be IID (0, $\sigma^2_{e(i)}$).

Henderson's method 3, the method of fitting constants (Henderson, 1953), was used to estimate the variances and covariances. In Henderson's method 3, it was assumed for computational purposes that all effects on the right hand side of these equations, except random error, were fixed. The LSML76 statistical package (Harvey, 1977) was employed in solving the equations and estimating the components of variance and covariance. By using the LSML76 statistical package, under model type (MTY) 02, there were two steps involved in estimating the variance and covariance components. The first step was to run the analysis using option NAB = 06, which meant that the random effects are ignored. The second run used option NAB = 02 and absorbed the equations for the Mu and the random effects into the equations for fixed effects other than Mu. Harvey (1977) called this method of solving the equations an "indirect" procedure which could achieve identical results as solving the normal equations (Harvey, 1970). The remainder sum of squares for a trait i, using this model, denoted as H_1, is computed as

$$H_1 = \sum_j \sum_k \sum_l Y^2_{ijkl} - R(Mu,F). \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where, the "R" notation refers to the reduction in the sum of squares due to fitting the terms within the parenthesis. The next step computes the remainder sum of squares from fitting the complete model (equation 1). The remainder sum of squares from the analysis under the complete model, denoted as H_2, can be written as

$$H_2 = \sum_j \sum_k \sum_l Y^2_{ijkl} - R(Mu,S,F). \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

Hence, the adjusted sum of squares for the sire effects, (SSq(S)), was computed by the indirect procedure as,

$$SSq(S) = H_1 - H_2 \text{ which is equivalent to,}$$

$$SSq(S) = R(Mu,S,F) - R(Mu,F). \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 4$$

The least-squares analysis of variance and covariance table (Harvey, 1977) can be written as in table 5. In table 5, ϕ^2_F is the variation due to the set of fixed effects.

TABLE 5. ANALYSIS OF VARIANCE AND COVARIANCE FOR BIRTH WEIGHT, WEANING WEIGHT, AND PREWEANING AVERAGE DAILY GAIN

Source of Variation	Sum of Squares and Sum of Cross Product	Expected Mean Squares	Expected Mean Cross Product
S(random)	$R(Mu,S,F) - R(Mu,F)$	$\sigma^2_e + k_1 \sigma^2_S$	$COV_{e(i,i')} + k_1 COV_{S(i,i')}$
F(fixed)	$R(Mu,S,F) - R(Mu,S)$	$\sigma^2_e + k\,\phi^2_F$	$\sigma^2_e + k\,\phi^2_F$
Error	$\sum_j \sum_k \sum_l y^2_{ijkl} - R(Mu,S,F)$	σ^2_e	$COV_{e(i,i')}$

The sum of squares is equated to their expectations to solve for ϕ^2_e and σ^2_S, thus we need to know k_1 which is computed as

$$k_1 = \frac{1}{d.f.(S)} (N - (\sum_i n^2_i)/N). \quad \ldots\ldots\ldots\ldots \; 5$$

Where, N is the total number of observations and n_i is the number of observations for the i^{th} sire. The variance component for sires, denoted σ^2_S, is then computed as,

$$\sigma^2_S = \frac{MS_S - MS_E}{k_1} . \qquad \ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where, MS_S and MS_E are the computed mean squares for the effects of the sire and the error terms, respectively, and k_1 is coefficient for the sire variance of the i^{th} trait. The size of the variance component, σ^2_S, is determined by the differences of the trait measured on calves sired by different sires.

Covariance components are required to estimate genetic correlations. These covariances were obtained from the analysis using the same model (equation 1) as those for the analysis of variance. Covariance components can be obtained at the same time as those for variance components. Instead of having only one trait as the dependent variable, birth weight, weaning weight, and preweaning average daily gain are fit together. The two trait covariances in this study were birth weight and weaning weight, birth weight and preweaning average daily gain, and weaning weight and preweaning average daily gain. Covariance components of trait i and i' for sire ($COV_{S(i,i')}$) and for error ($COV_{e(i,i')}$) were estimated by equating the observed sum of cross products to their expectation, and solving for the covariances. Sire covariance is computed as,

$$COV_{S(i,i')} = \frac{MCP_S - MCP_E}{k_1} . \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

Where, MCP_S and MCP_E are the computed mean crossproducts for the effects of the sire and the error terms, respectively. These estimates were used in the development of formulae for phenotypic and genetic correlations which are presented in the following sections.

Estimation of parameters

The parameters to be estimated are heritabilities (h^2), genetic correlations (r_G), and phenotypic correlations (r_P). The reliability of each estimate was measured by calculating approximate standard errors and confidence limits.

Heritability. The general formula for heritability based on paternal half sib intraclass correlation is

$$h^2_S = 4\,\sigma^2_S/(\,\sigma^2_T\,). \qquad \text{.................. } 8$$

Where σ^2_T equals $\sigma^2_S + \sigma^2_e$. Four times the sire component of variance, σ^2_S, computed from paternal half sib covariance, which is assumed equaled to σ^2_A (additive genetic variance). It is generally known as heritability in narrow sense (Falconer, 1981) and is the ratio of additive genetic variance to total phenotypic variance. The assumptions imposed in estimating heritability are that sex linkage effects do not exist and that a large population size with random mating was the source of the data (Becker, 1984).

Standard error of h^2, denoted as S.E. (h^2_S), was calculated using an approximate method as outlined by Swiger et al. (1964) which can be expressed as,

$$\text{S.E. } (h^2_S) = 4 \sqrt{\frac{2\,(1 - t)^2\,[1 + (k_1 - 1)\,t]^2}{k_1(k_1 - 1)(M - 1)}} \quad \ldots\ldots\ldots 9$$

where t is the intraclass correlation, k_1 is the coefficient for the sire variance (in table 5), M is the total number of sires, and other symbols remain as previously described. The standard error of heritability obtained is considered as approximate because the unequal numbers of observations per sire.

Genetic and phenotypic correlations. Phenotypic correlations, r_P, were estimated using the formula,

$$r_P = \frac{COV_{S(i,i')} + COV_{e(i,i')}}{[(\sigma^2_{S(i)} + \sigma^2_{e(i)})(\sigma^2_{S(i')} + \sigma^2_{e(i')})]^{1/2}} \quad \ldots\ldots\ldots 10$$

where $COV_{S(i,i')}$ is the covariance due to the same sire. $COV_{e(i,i')}$ is the residual covariance between trait i and i'.

Genetic correlations were estimated as

$$r_G = COV_{S(i,i')}/[\,\sigma^2_{S(i)} \times \sigma^2_{S(i')}\,]^{1/2}. \quad \ldots\ldots\ldots 11$$

The variances of genetic and phenotypic correlations were formulated using an approximate formula (Robertson, 1959). The variance of the phenotypic correlation is expressed as,

$$\text{Var}(r_P) = \frac{(1 - r_P)^2 \times [\text{Var}(h^2_i) \times \text{Var}(h^2_{i'})]^{1/2}}{2h^2_i \times h^2_{i'}}. \quad \ldots\ldots 12$$

Where, $Var(r_P)$ is the phenotypic correlation, $Var(h^2_i)$ is the variance of heritability of trait i, and $Var(h^2_{i'})$ is the variance of heritability of trait i'. The approximate variance of the genetic correlation is obtained using a formula similar to that for the phenotypic correlation. To estimate the standard error of genetic correlation, r_P in equation 12 is replaced with r_G. By taking the square root of these two variances, the standard errors of the phenotypic and genetic correlation were obtained.

General selection index

The selection index equations given by Hazel (1943) are

$$\underset{\sim}{V}\underline{b} = \underset{\sim}{G}\underline{a} \qquad \text{........................ } 13$$

with two traits, $\underset{\sim}{V}$ is the phenotypic covariance matrix of size 3 x 3, $\underline{b}$ is 3 x 1 vector of selection index coefficients, $\underset{\sim}{G}$ is a 3 x 3 matrix of genetic covariances due to additive gene action, and $\underline{a}$ is a 3 x 1 vector of relative economic values. Solution of these equations gives estimates of $\underline{b}$;

$$\underline{\hat{b}} = \underset{\sim}{V}^{-1}\underset{\sim}{G}\underline{a} \qquad \text{........................... } 14$$

For any animal, the index for trait i is

$$I_i = b_1P_1 + b_2P_2 + b_3P_3. \qquad \text{...................... } 15$$

Where, P_i is a measure of the animal's performance as a deviation from all fixed effects pertaining to the record according to model 1 on page 29.

Mathematical properties of the selection index were given by Henderson (1952) and Williams (1962). Henderson (1963) showed that the selection index procedure is the best linear prediction (BLP).

To obtain unrestricted selection indices, the phenotypic and genetic covariances required were obtained from the results of the earlier analyses of variance and covariance components. The relative economic values were obtained using a multiple regression technique which will be explained later.

Restricted selection index

In practice, a breeder might like to affect changes in the means of some traits while leaving others unchanged. This applies to beef cattle when a breeder wishes to hold birth weight constant while improving weaning weight. Kempthorne and Nordskog (1959) described restricted index selection where the coefficients for the restricted index were computed as

$$\underline{\hat{b}} = [\, \underset{\sim}{I} - \underset{\sim}{V}^{-1}\underline{\underset{\sim}{G}c}\,(\underline{c}'\underset{\sim}{G}\underset{\sim}{V}^{-1}\underline{\underset{\sim}{G}c})^{-1}\underline{c}'\underset{\sim}{G}\,]\,\underset{\sim}{V}^{-1}\underline{\underset{\sim}{G}a} \;\ldots\ldots\ldots\ldots\ldots\ldots\; 16$$

where, $\underset{\sim}{I}$ = an identity matrix,

$\underset{\sim}{G}$ = the genotypic variance and covariance matrix of birth weight, weaning weight, and preweaning average daily gain,

$\underset{\sim}{V}^{-1}$ = the inverse of the phenotypic variance and covariance matrix,

$\underline{c}$ = vector of coefficients necessary for making the restrictions on the index, and

$\underline{c}'$ = the transpose of $\underline{c}$.

If a restriction is placed on the first trait, x_1, while the other two, x_2 and x_3, are unrestricted, the appropriate $\underline{c}'$ vector is (1 0 0). It is apparent from equation 16 that if the vector of coefficients for the restricted index was (0 0 0) are utilized that it reduces to the classical selection index, i.e., $\underset{\sim}{V}^{-1}\underset{\sim}{G}\underline{a}$. Equation 16 was used to construct restricted indices.

Efficiency of an index

The correlation between index values (I) and true genetic worth (H) is r_{IH} which provides a measure of the efficiency of an index. The higher the correlation, the better the index is as a predictor of breeding values. If H indicates additive genetic value, the fraction of additive genetic variance that is not accounted for by the index equals $1-r^2_{IH}$. In the present study, both r_{IH} and $1-r^2_{IH}$ were estimated. The value of r^2_{IH} is computed (Lin, 1978) as

$$(\underline{a}'\underset{\sim}{G}\underline{b})^2/(\underline{a}'\underset{\sim}{G}\underline{a})\times(\underline{b}'\underset{\sim}{V}\underline{b}). \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 17$$

The quantity r_{IH} for a restricted selection index was derived by Kempthorne and Nordskog (1959) as the following expression

$$r_{IH} = [\underline{a}'\underset{\sim}{G}\{\underset{\sim}{I} - \underset{\sim}{V}^{-1}\underset{\sim}{G}\underline{c}(\underline{c}'\underset{\sim}{G}\underset{\sim}{V}^{-1}\underset{\sim}{G}\underline{c})\}\underset{\sim}{V}^{-1}\underset{\sim}{G}\underline{a}]^{1/2}. \quad \ldots\ldots\ldots\ldots\ldots \; 18$$

Estimation of response to selection

Response to selection was estimated using the expression given by Lin (1978) as

$$\underline{f} = i \times (\underset{\sim}{G}\underline{b})/(\underline{b}\underset{\sim}{V}\underline{b})^{1/2}. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 19$$

Above, $\underline{f}$ is a column vector of genetic gains corresponding to each trait contained in the index, i is the selection intensity, $\underset{\sim}{G}$ is a genetic covariance matrix. Selection intensity, i, was measured by the average superiority of the selected parents over that of the based population (selection differential) and standardized by dividing the phenotypic standard deviation. Given that i_m and i_f are the selection intensities for male and female calves to be selected as the parents, then the i_e, the effective selection intensity, equaled 1/2 x $(i_m + i_f)$.

Estimation of relative economic values

In this study the economic values of birth weight, weaning weight, and preweaning average daily gain were calculated using multiple regression. Total gross income at weaning per cow per year was regressed on average birth weight, weaning weight, and preweaning average daily gain each year. The number of independent measures of the growth traits to be regressed on total gross income, two or three, depends on the number of traits used in the index. Production per cow each year was a linear function of average weaning weight of the calves and average number of calf wean. Multiple regression of gross income on birth weight, weaning weight, and preweaning average daily gain is expressed as

$$Y_i = \overline{Y}. + a_1(X_{1i} - \overline{X}_{1.}) + a_2(X_{2i} - \overline{X}_{2.}) + a_3(X_{3i} - \overline{X}_{3.}) + e_i. \quad \ldots 20$$

Where, Y_i = the gross income per cow for year i, and i = 1, 2, 3,..., 15. Y_i equals the product of average weaning weight of calves for the i^{th} year x weaning rate x price of calf per kilogram,

a_1 = the relative economic value for birth weight,

a_2 = the relative economic value for weaning weight,

a_3 = the relative economic value for preweaning average daily gain,

X_{1i} = the average birth weight of calves born in year i,

X_{2i} = the average weaning weight of calves born in year i,

X_{3i} = the average preweaning average daily gain of calves born in year i,

e_i = the random error, assumed NID $(0, \sigma^2_e)$.

An assumption was made that production per cow each year was the result of the combined effects of the cow's reproductive performance and the calf's ability to grow. Relative economic values for birth weight, weaning weight, and preweaning average daily gain were defined as the amount of total income received from increasing birth weight, weaning weight, or preweaning average daily gain by one unit weight (one kilogram for birth weight and weaning weight, and one gram for preweaning average daily gain), while holding the other two traits not being considered constant.

The average value of calves was $.794 per kilogram for gross income over the 15 year period with a range of $.571 to $1.951 per kilogram as shown in table 6. Regressing gross income per year on birth weight, weaning weight, and preweaning average daily gain will give us relative economic values for these three traits. In the same manner, if the incex is based on two traits, multiple regression could be done using the two traits in order to obtain the relative economic values from the partial regression coefficients.

Results and Discussion

The most important aspect of this study was the development of the restricted and unrestricted selection indices. Also useful was the estimation of phenotypic and genetic variances and covariances. For simplicity of presentation, factors affecting the three preweaning growth traits, variance and covariances, genetic and phenotypic parameters will be discussed first. Then, the results of the development of selection indices together with the predicted responses will be presented.

Factors Affecting Preweaning Growth Traits

Factors affecting birth weight (BW), weaning weight (WW), and preweaning average daily gain (PADG) were obtained from the analyses of data collected during the years 1965 to 1979. Data sets with male calves, female calves, and both sexes combined were investigated to

TABLE 6. PRICE OF CALF PER KILOGRAM, ARITHMETIC MEANS OF WEANING WEIGHT AND WEANING RATE OVER A 15-YEAR PERIOD

Year	Price ($)[a]	Weaning weight	Weaning rate
1965	.484	187.63	.775
1966	.571	192.76	.844
1967	.581	173.24	.706
1968	.605	192.86	.570
1969	.692	180.58	.748
1970	.759	174.99	.829
1971	.799	178.15	.887
1972	.982	178.01	.876
1973	1.244	186.10	.768
1974	.774	195.16	.818
1975	.600	179.14	.650
1976	.750	189.96	.705
1977	.813	195.16	.818
1978	1.302	196.43	.808
1979	1.951	197.91	.803

[a] Florida Agricultural Statistics, 1984.

determined the major factors affecting the traits. Appendix tables 32 through 34 show factors affecting birth weight while appendix tables 35 to 37 and tables 38 to 40 show those factors affecting weaning weight and preweaning average daily gain, respectively. The effects included in the models were sire effects, year of calf birth, sex of calf, age of dam, and age of calf (for weaning weight and preweaning average daily gain). Results of these effects on the three traits under study were as follows.

Sire effects

There were sire effects ($P<.01$) on birth weight, weaning weight, and PADG in all categories based on the analyses of the male, female, and combined sexes of calves data sets. Significant sire effects in British breeds have also been reported by Brown (1960), Thrift et al. (1970), Dinkel and Busch (1973), Pani et al. (1977) and Pacho (1981).

Year of calf birth

Significant year of calf birth effects were found in all analyses. The significant effects of year of calf birth on preweaning growth traits are in agreement with results reported by numerous authors including Swiger et al. (1961), Brown et al. (1972), and Pacho (1981).

Sex of calf

Sex of calf had an effect ($P<.05$) on birth weight, weaning weight, and PADG. Bull calves were heavier than the heifer calves at all ages and gained more per day until weaning. This finding was in agreement with the reports of Brown (1960), Blair et al. (1972), Gregory et al. (1979) and Euclides (1984).

Age of dam

Dam age had significant effects (P<.01) on BW, WW, and PADG in this study (appendix tables 32 to 40) in all sexes groups. A cow got older, they tended to produce heavier calves. This phenomenon was true up to 6 years of age and then the weaning weights of their calves began to decline. The significant age of dam effects from this study are in agreement with results obtained from British breeds (Mahmud and Cobb, 1963; Boston et al., 1975; Williams et al., 1979; Pacho, 1981; Euclides, 1984).

Age of calf

Age of calf had no effect (P>.05) on weaning weight and PADG in this study. The maximum difference of calf age was no more than 80 days. Gregory et al. (1950) reported that when the variation in age of individuals was not more than 90 days, age of calf could be ignored in evaluating postweaning traits. However, Wilson et al. (1972), recommended adjustment for age of calf in analyses of weaning weight. Many reports have shown significant effects of age of calf on weaning weight (Lasley et al., 1961; Wilson et al., 1972; Holland et al., 1977; Euclides, 1984).

Estimates of Parameters

The parameters to be estimated in this study were the variances and covariances of the phenotypic and genetic sources of variation, heritabilities, and phenotypic and genetic correlations among the traits studied. Each estimate will be presented with its approximate standard error.

Variance and covariance components

Phenotypic variance and covariance components for birth weight, weaning weight, and PADG are shown in tables 7 through 9 for the within male calves, within female calves, and within combined sexes data sets. The genetic components are shown in tables 10 through 12 for the three data sets. The results of the analyses will be presented separately as phenotypic and genetic sources of variation.

Phenotypic variance and covariance components.

Phenotypic variance and covariance components for birth weight, weaning weight, and preweaning average daily gain are shown in tables 7, 8, and 9 for the within male, the within female, and combined calf sex analyses.

Phenotypic variance components for birth weight were found to be 12.5, 12.1, and 12.3 from the within male calves, within female calves, and within combined sex analyses, respectively. The phenotypic variance components for weaning weight and PADG within the three analyses were 364.4, 292.5, and 343.9 and .0063, .0047, and .0058, respectively. It was seen, in general, that the combined sex analyses for the three growth traits had an intermediate amount of variation, between those of each of the sexes analyzed separately. The covariance components between birth weight and weaning weight within the three respective group of analyses were found to be 27.05, 28.65, and 27.54. The covariance components between birth weight and PADG were .065,

TABLE 7. PHENOTYPIC VARIANCE AND COVARIANCE COMPONENTS FOR PREWEANING GROWTH TRAITS FROM THE WITHIN MALE CALVES ANALYSIS[a]

	Birth weight	Weaning weight	Preweaning average daily gain
Birth weight	12.5079	27.0469	.0649
Weaning weight		364.4249	1.4778
Preweaning average daily gain			.0063

[a] Variances are on the diagonal and off diagonal elements indicate covariances.

TABLE 8. PHENOTYPIC VARIANCE AND COVARIANCE COMPONENTS FOR PREWEANG GROWTH TRAITS FROM THE WITHIN FEMALE CALVES ANALYSIS[a]

	Birth weight	Weaning weight	Preweaning average daily gain
Birth weight	12.1236	28.6496	.0726
Weaning weight		292.4978	1.1426
Preweaning average daily gain			.0047

[a] Variances are on the diagonal and off diagonal elements indicate covariances.

TABLE 9. PHENOTYPIC VARIANCE AND COVARIANCE COMPONENTS FOR PREWEANING GROWTH TRAITS FROM THE WITHIN COMBINED SEXES OF CALVES ANALYSIS[a]

	Birth weight	Weaning weight	Preweaning average daily gain
Birth weight	12.3376	27.5428	.0764
Weaning weight		343.9526	1.3791
Preweaning average daily gain			.0058

[a] Variances are on the diagonal and off diagonal elements indicate covariances.

.073, and .076. The covariances between weaning weight and PADG within the three sex groups were found to be 1.478, 1.143, and 1.380, respectively. Similar ranges of phenotypic variance and covariance components were reported by Koch and Clark (1955), Brinks et al. (1962), Koch et al. (1973), Wilkes (1983) and Skaar (1985).

Genetic variance and covariance components. The estimates of genetic variance and covariance components are shown in tables 10, 11, and 12 for the within male, within female, and combined sex analyses, respectively. The genetic variance components for birth weight within male and female calves were found to be very similar (4.24 from male calves and 4.47 from female calves) while a lower estimate of 3.16 was obtained from the combined sex analysis. The variance component for weaning weight was lowest at 58.74 when estimated from the within female calves analysis; a medium value of 124.10 was obtained from the combined sex analysis, while the highest value of 195.69 was found from the within male calves analysis. The same pattern was found in the components of variance for PADG within these three groups. The estimates of these respective genetic components of variance for PADG were found to be .0007, .0021, and .0031, respectively. The genetic covariance components between birth weight and weaning weight for the three groups were found to be 15.69, 9.53, and 7.08. The genetic covariance between preweaning growth traits varied from each other to some extent. The covariance components between birth weight and PADG and between weaning weight and PADG within male, female, and combined sex of calves analyses were .046 and .016, .014 and .760 and .190 and .480, respectively. Dunn et al. (1970) and Vesely and Robison (1971)

TABLE 10. GENETIC VARIANCE AND COVARIANCE COMPONENTS FOR PREWEANING GROWTH TRAITS FROM THE WITHIN MALE CALVES ANALYSIS[a]

	Birth weight	Weaning weight	Preweaning average daily gain
Birth weight	4.2423	15.6892	.0458
Weaning weight		195.6859	.7607
Preweaning average daily gain			.0031

[a] Variances are on the diagonal and off diagonal elements indicate covariances.

TABLE 11. GENETIC VARIANCE AND COVARIANCE COMPONENTS FOR PREWEANING GROWTH TRAITS FROM THE WITHIN FEMALE CALVES ANALYSIS[a]

	Birth weight	Weaning weight	Preweaning average daily gain
Birth weight	4.4701	9.5289	.0165
Weaning weight		58.7416	.1869
Preweaning average daily gain			.0007

[a] Variances are on the diagonal and off diagonal elements indicate covariances.

TABLE 12. GENETIC VARIANCE AND COVARIANCE COMPONENTS FOR PREWEANING GROWTH TRAITS FROM THE WITHIN COMBINED SEXES OF CALVES ANALYSIS[a]

	Birth weight	Weaning weight	Preweaning average daily gain
Birth weight	3.1654	7.0758	.0138
Weaning weight		124.0908	.4844
Preweaning average daily gain			.0020

[a] Variances are on the diagonal and off diagonal elements indicate covariances.

reported genetic variance and covariance components within the range found in this study.

Heritability estimates. The heritability estimates for birth weight (BW), weaning weight (WW), and preweaning average daily gain (PADG) are shown in table 13 along with their approximate standard errors. The results will be presented separately for BW, WW, and PADG.

Heritabilities of .34±.13, .37±.15, and .26±.08 were obtained from the analyses of birth weight within male calves, within female calves, and in the combined calf sex analyses, respectively. These results were based on paternal half-sib analyses (equation 1) as described in the model description and statistical analyses. Very similar estimates of heritability for birth weight have been reported by many authors (Knapp and Clark, 1950; Dawson et al., 1954; Swiger et al., 1962; Marlowe and Vogt, 1965; Koch, 1972; Bourden and Brinks, 1982; Nelsen et al., 1984; Skaar, 1985). Higher estimates were reported by Rollins and Guillbert (1954), Everett and Magee (1965), Dunn et al. (1970), and Koger et al. (1975).

There were differences in the heritability estimates for weaning weight obtained from the sexes analyzed separately. A medium estimate of .54±.14 was found from the male calves analysis whereas a low estimate of .20±.14 was obtained from the female calves analysis. The combined sex data set gave an estimate of .36±.09. If standard errors, as compared to estimates of heritabilities, are considered as the measure of accuracy, it can be seen that estimate of heritability obtained from the within female calves analysis had a lower accuracy than that of the other two groups. Gregory et al. (1950) and Vesely

TABLE 13. HERITABILITIES FOR PREWEANING GROWTH TRAITS WITH THEIR STANDARD ERRORS FROM MALE, FEMALE, AND COMBINED SEXES OF CALVES ANALYSES

Sex/Trait	Estimate	SE[a]
Male:		
Birth weight	.339	.128
Weaning weight	.537	.142
Preweaning average daily gain	.495	.140
Female:		
Birth weight	.369	.150
Weaning weight	.201	.138
Preweaning average daily gain	.147	.134
Combined:		
Birth weight	.257	.079
Weaning weight	.361	.088
Preweaning average daily gain	.346	.087

[a] Standard error.

and Robison (1971) reported the heritability of birth weight to be around .50, similar to that of the within male calves analysis in this study. Estimates between .25 and .35 have been reported by many authors (Swiger, 1961; Hill, 1965; Minyard and Dinkel, 1965; Koch et al., 1973).

The estimate of heritability of PADG was found to be .49±.14 from the within male calves analysis. A lower heritability estimate of .15±.13 was obtained from the within female calves analysis. In the combined sexes of calves analysis, an intermediate estimate of .35±.09 was obtained. Shelby et al. (1955) and Warwick and Cartwright (1955) reported a heritability of PADG of around .40, whereas lower estimates were found by other authors (Pahnish et al., 1964; Hallman, 1966; Deese and Koger, 1967). Estimates higher than .40 have also been documented by many authors (Shelby et al., 1955; Brown and Maximo, 1963; Brinks et al., 1964; Chapman et al., 1972).

There were no extraordinarly large standard errors in any of the estimates. Therefore, further usage of these parameters is warranted since the ranges were found to be within the normal ranges for all of the estimates.

Phenotypic correlations. The phenotypic correlations among the three growth traits and their standard errors are shown in table 14. The phenotypic correlations between birth weight and weaning weight were found to be around .45 for all three groups (.48±.17 in the male, .48±.41 in the female, and .42±.16 in the combined sex analyses). The phenotypic correlations that were obtained between birth weight and PADG in the respective three groups were .23±.22, .31±.61, and .25±.18

TABLE 14. PHENOTYPIC CORRELATIONS AMONG PREWEANING GROWTH TRAITS BY MALE, FEMALE, AND COMBINED SEXES OF CALVES ANALYSES

Sex/Trait	Weaning weight		Preweaning average daily gain	
	Estimate	SE	Estimate	SE
Male:				
Birth weight	.481	.172	.231	.218
Weaning weight			.977	.108
Female:				
Birth weight	.481	.406	.305	.307
Weaning weight			.975	.867
Combined:				
Birth weight	.423	.159	.252	.184
Weaning weight			.976	.260

whereas these correlations between weaning weight and PADG were found to be .977±.108, .975±.867, and .976±.260, respectively. There are numerous reports that agree with the estimates obtained from this study (Shelby et al., 1963; Pahnish et al., 1964; Chapman et al., 1972; Stewart, 1974; Pacho, 1981). However, higher estimates of phenotypic correlations between these growth traits were reported by Koch and Clark (1955), Panish et al. (1964), Dunn et al. (1970), and Koch et al. (1973). It was noticed from the results in this study that the standard errors of the estimates obtained within female calves analyses were all especially high which suggested that there were low reliabilities of the phenotypic correlations within this sex group. Therefore, careful consideration should be given when applying these correlations in selection indices.

Genetic correlations. The genetic correlations and their standard errors were presented in table 15. The genetic correlations between birth weight and weaning weight were all moderate (.55±.16 in the male, .59±.24 in the female, and .36±.17 in the combined sex analyses). Lower estimates were found for the genetic correlations between birth weight and PADG, .40±.19, .30±.39, and .17±.19 from the within males, within females, and combined sex analyses, respectively. The genetic correlations between weaning weight and PADG were .98±.11, .93±.14, and .97±.11, from the three analyses, respectively. The results obtained in the present study, in spite of high standard errors within the female calves analyses, yielded estimates within the ranges reported by most researchers (Brinks et al., 1973; Dunn et al., 1970; Koch et al., 1973; Tumwasorn et al., 1977; Pacho et al., 1981.

TABLE 15. GENETIC CORRELATIONS AMONG PREWEANING GROWTH TRAITS BY MALE, FEMALE, AND COMBINED SEXES OF CALVES ANALYSES

Sex/Trait	Weaning weight		Preweaning average daily gain	
	Estimate	SE	Estimate	SE
Male:				
Birth weight	.546	.155	.399	.195
Weaning weight			.975	.109
Female:				
Birth weight	.588	.236	.298	.392
Weaning weight			.929	.139
Combined:				
Birth weight	.357	.169	.173	.191
Weaning weight			.971	.110

Results of Selection Index Construction

The construction of selection indices yielded three types of information. The first was the estimation of relative economic values for birth weight, weaning weight, and preweaning average daily gain using a regression technique. The second was the estimation of beta values or the coefficients of each component trait to include in linear combinations of traits in the indices. The last was the development of selection indices containing varying linear combinations of traits. Due to the high genetic correlation between weaning weight and preweaning average daily gain, possible effects of multicollinearity may give undesirable coefficients for PADG and WW if they are considered together in the same index. Therefore, only indices of birth weight and weaning weight were developed within sexes and for the combined sexes.

Estimates of relative economic values

The relative economic values obtained from regressing gross income on birth weight, weaning weight, and preweaning average daily gain are presented in table 16. These values vary considerably from index to index depending on the number of traits included in the index. The coefficients of multiple determination which usually explain how much of the variation in the traits is accounted for by any given combination of independent variables are also shown in table 16. The relative economic values for the index that included all three traits (index no. 1) were found to be -\$.724, \$.099, and \$.024 per one kilogram increase in BW and WW, and per one gram increase in PADG, respectively. The relative economic values from the index containing

TABLE 16. RELATIVE ECONOMIC VALUES FOR SEVERAL LINEAR COMBINATIONS OF PREWEANING GROWTH TRAITS USED IN THE CONSTRUCTION OF SELECTION INDICES

Index no	Relative economic value			R^a
	Birth weight	Weaning weight	Preweaning average daily gain	
1	-.7241	.0988	.0244	.531
2	-.8091	.1711		.489
3	-.5339		.0400	.494
4		.0378	.0303	.440

[a] (coefficient of multiple determination)$^{1/2}$.

only birth weight and weaning weight (index no. 2) were -\$.809 and \$.171 per kilogram increase in BW and WW, respectively. These changes in economic values are reasonable if it is considered that the magnitude of each relative economic values would be increased when less variables are included in the index. When only birth weight and PADG were included in the index (index no. 3), these economic values were found to be -\$.534 per one kilogram increase in weaning weight and \$.040 per gram increase in PADG. The corresponding relative economic values for the combination of weaning weight and PADG in this analyses resulted in \$.038 per one kilogram increase in weaning weight and \$ .030 per one gram increase in PADG. The coefficients of multiple determination for indices 1 through 3 were similar with an average of .50; a lower value as obtained from index no 4 (.44).

The relative economic values for birth weight and weaning weight obtained from the analyses of these data showed relatively the same range of magnitude as those reported by many authors (Lindholm and Stonaker, 1957; Lehman et al., 1961; Vesely and Robinson, 1971). However, the economic values for any index that involved PADG yielded extraordinarily different results as compared to the literature average. This can apparently be explained due to the multicollinearity effects between weaning weight and preweaning average daily gain.

Selection index

Selection indices involving birth weight and weaning weight within males, females, and combined sexes of calves were shown in tables 17. Within each sex group, index number 1 refers to the general selection index whereas index number 2 refers to the restricted selection index.

The restricted indices in this study were developed such that birth weight was held constant while allowing weaning weight to increase. It was seen, in general, that the beta values (coefficients of the traits included in the index) for birth weight in restricted indices were lower than these values for birth weight in unrestricted ones. This indicates that the restriction procedure was successful.

It is seen in table 17 that the correlation between aggregate genetic worth and the index (R_{IH}) is higher in the male and combined sex groups than in the female group. This suggests that the selection index for the female calves is less reliable than those developed for the male calves and the combined sex of calf group.

Responses to selection

Once the estimates of genetic and phenotypic parameters are obtained, these estimates can be further used as inputs in developing formulae used in evaluating animals based on genetic superiority. The response to selection can also be predicted using these formulae. The term "selection response" in this study is defined as a measure of genetic improvement in offspring after selection had been made on the parents. Responses in birth weight, weaning weight, and preweaning average daily gain are predicted using two different units, actual units of kilogram per generation and in terms of phenotypic standard deviation units.

Predicted genetic gains from unrestricted selection indices. The expected genetic responses from selection based on unrestricted selection indices per one unit of selection intensity are shown in

TABLE 17. BETA BALUES FOR LINEAR COMBINATIONS OF TRAITS USED IN CONSTRUCTION OF SELECTION INDICES WITHIN MALE, FEMALE, AND COMBINED SEXES OF CALVES

Sex/Index[a]	Birth weight	Weaning weight	R_{IH}	$1 - R^2_{IH}$
Male:				
1	.289	3.062	.733	.463
2	-8.870	2.401	.739	.454
Female:				
1	.953	1.903	.467	.782
2	-.003	.848	.407	.834
Combined:				
1	-1.968	2.243	.608	.630
2	-5.009	2.242	.765	.415

---

[a] 1 = unrestricted selection index and 2 = selection index restricted on birth weight.

table 18. These predicted responses are reported within bulls, heifers, and combined sex groups. The expected genetic responses per generation of index selection for birth weight and weaning weight were .844 and 10.347 kg, respectively, within male calves. These responses in terms of phenotypic standard deviation were .211 and .413 σ_P, respectively. In general, it was found that the expected genetic responses obtained from the females were less than those obtained from the males except for birth weight. The combined sex analyses yielded intermediate estimates, as would be expected. The predicted genetic gains for birth weight and weaning weight within the females were found to be .874 and 3.678 kg with values of .241 and .156 phenotypic standard deviation units. The genetic gains of these two traits within the combined sexes were found to be .248 and 6.810 kg. The corresponding response in standard measure per unit of selection intensity for the response of birth weight and weaning weight within female calves were found to be .064 and .271 σ_P, respectively.

In real situations, different selection intensities are given to the different sexes, or in other words, the proportions of animals are selected as breeding stock are different in the different sexes. Fewer male calves are needed as bulls than the number of females selected to be future dams. In this study, we assumed that 5% of the male calves were selected as the bulls based on weight at 20 months old and postweaning gain whereas 80% of the female calves were selected as future dams. The selection intensities for these two sex groups were found to be 2.008 and .341 for males and females, respectively.

The expected genetic gains using index selection within male, female, and combined sexes of calves are shown in table 19. Genetic

TABLE 18. PREDICTED GENETIC RESPONSES TO SELECTION BASED ON AN UNRESTRICTED SELECTION INDEX FROM LINEAR COMBINATION OF BIRTH WEIGHT AND WEANING WEIGHT BY MALE, FEMALE, AND COMBINED SEXES OF CALVES[a]

Sex	Birth weight	Weaning weight
Male	.844[b] .221[c]	10.347 .413
Female	.874 .241	3.678 .156
Combined	.248 .064	6.810 .271

---

[a] Genetic gain based on one unit of selection intensity.

[b] In kilogram per generation.

[c] In unit of phenotypic standard deviation per generation.

gains within male for birth weight and weaning weight were found to be .764 and 9.360 kg per generation while the gains of these two traits were .134 and 1.657 kg from the within female analyses. The corresponding gains in standard measures for within males and females for these two traits were .200 and .373, and .037 and .071 σ_P, respectively. The results of genetic gains expected from mating selected males and females under the assumed selection intensities for each sex were found to be .195 and 5.353 kg per generation with the standard measure of .051 and .213 σ_P for birth weight and weaning weight, accordingly.

The results obtained using unrestricted selection indices to predict the genetic gains from birth weight and weaning weight in this study agreed with the reports of many authors (Dickerson et al., 1974; Koch et al., 1974; Van Vleck et al., 1977; Mendoza and Slanger, 1985).

The time spent in the development of selection indices is wasted if, once developed, they are never applied by beef cattle producer. In this study an appropriate index will be recommended for further application. There are 3 indices to be considered in this study. They are indices based on two traits (birth weight and weaning weight) that can be used for within bull calves, within female calves, and that for combined sexes. Indices for bull calves and the combined sex are highly recommended due to their small standard errors for the variance and covariance components obtained. It is well understood that genetic correlations are very sensitive to environmental changes (Falconer, 1981 and Pirchner, 1983), therefore, the genetic and phenotypic correlations used in constructing selection indices should have minimum standard errors as compared to their estimates. Unfortunately,

TABLE 19. PREDICTED GENETIC RESPONSES BASED ON A SELECTION INDEX OF A LINEAR COMBINATION OF BIRTH WEIGHT AND WEANING WEIGHT WITHIN MALE, FEMALE, AND COMBINED SEXES OF CALVES[a]

Sex/trait	Actual unit[b]	Standard measure[c]
Male:		
Birth weight	.764	.200
Weaning weight	9.360	.373
Female:		
Birth weight	.134	.037
Weaning weight	1.654	.071
Combined:		
Birth weight	.195	.051
Weaning weight	5.353	.213

[a] Proportion selected for males is .05 with selection intensity of 2.008.

Proportion selected for females is .80 with selection intensity of .341,

Effective selection intensity is 1.175 for the combined sexes of calves.

[b] In kilogram per generation.

[c] In unit of phenotypic standard deviation per generation.

the selection index for female calves developed in this study was obtained through the use of genetic correlations with high standard errors, and thus the index for the female calves may be less effective. The unrestricted selection indices based on birth weight and weaning weight are;

I = .10(Birth weight-25.6) + (Weaning weight-190.1) 21

I = .50(Birth weight-23.7) + (Weaning weight-177.9) 22

I = -.88(Birth weight-24.7) + (Weaning weight-184.5) 23

where index equation 21 is for the selection index of male calves and indices 22 and 23 are for use in selection of female calves and combined sex selection, respectively. In practice, the recommended selection index to be used for both males and females is the index for the combined sex (equation 23).

Predicted genetic gains from restricted selection indices. The predicted genetic gains from restricted indices within the three sex groups measured per one unit of selection intensity are shown in table 20 whereas table 21 shows response to selection using different selection intensities are applied in each sex.

The within male calves analyses (table 21) showed that the expected genetic gains would be 0 and 6.800 kg with corresponding standard measures of 0 and .273 σ_P per generation for birth weight and weaning weight. The analyses within female calves (table 21) showed the expected genetic gain to be lower than those expected from the male calves. The genetic gain within the female group were found

TABLE 20. PREDICTED GENETIC RESPONSES TO SELECTION BASED ON A SELECTION INDEX FOR BIRTH WEIGHT AND WEANING WEIGHT RESTRICTED ON BIRTH WEIGHT BY MALE, FEMALE, AND COMBINED SEXES OF CALVES[a]

Sex	Birth weight	Weaning weight
Male	0	7.516[b]
	0	.299[c]
Female	0	3.413
	0	.145
Combined	0	6.442
	0	.256

---

[a] Genetic response based on one unit of selection intensity.
[b] In kilogram per generation.
[c] In unit of phenotypic standard deviation per generation.

TABLE 21. GENETIC RESPONSES TO SELECTION BASED ON AN INDEX FOR BIRTH WEIGHT AND WEANING WEIGHT RESTRICTED ON BIRTH WEIGHT WITHIN MALE, FEMALE, AND COMBINED SEXES OF CALVES[a]

Sex/trait	Actual unit[b]	Standard measure[c]
Male:		
Birth weight	0	0
Weaning weight	6.800(72.6)[d]	.273
Female:		
Birth weight	0	0
Weaning weight	.529(31.9)	.022
Combined:		
Birth weight	0	0
Weaning weight	5.110(95.5)	.200

[a] Proportion selected for male is .05 with selection intensity of 2.008.

Proportion selected for female is .80 with selection intensity of .341.

[b] In kilogram per generation.

[c] In unit of phenotypic standard deviation per generation.

[d] In bracket is the predicted response in percent of that obtained from using the unrestricted index.

to be 0 and .529 kg with standard measures of 0 and .022 σ_p per generation for birth and weaning weight, respectively. When the combined sex analyses were employed, the expected genetic gains for these two growth traits and their standard measures were 0 and .511 kg and 0 and .200 σ_p, respectively. The expected genetic gains obtained from the three sex groups using restricted selection indices were found to be within the ranges reported by many authors (Dickerson et al., 1974; Lin, 1978; Bourdon and Brinks, 1982; Mendoza and Slanger, 1985). In this study, predicted genetic gains in weaning weight within bulls, heifers, and combined sex groups using restricted indices were found to be 72.6, 31.9, and 95.5% of those obtained from using the unrestricted indices.

A restricted index (I) of I = yearling weight - 3.2 x birth weight was suggested by Dickerson et al. (1974). Later, Bourdon and Brinks (1982) developed the index: I = yearling weight - 7.82 x birth weight. In both indices, birth weight was restricted. These indices have advantage that they are simple to apply by producers. However, the disadvantage of both is that animals have to be retained until yearling weights are recorded. Recently, Mendoza and Slanger (1985) presented various indices that restrict birth weight while allowing weaning weight to improve or, in another words, selection was aimed at changing the growth curve. Mendoza and Slanger did not estimate phenotypic and genetic parameters from a specific population but instead used parameters based on literature averages. By varying the genetic correlation between birth weight and weaning weight, Mendoza and Slanger obtained indices where the coefficent for birth weight used in the indices ranged from -2.66 to -1.58. In this study, the genetic and phenotypic parameters were estimated from the herd in which selection was applied, therefore, the most appropriate estimates should have been obtained which should increase the utility of the index when applied to this herd in the future. The recommended indices obtained from this study that restrict birth weight are those for within males and within combined sex of calf indices. The index for selection of the females has less accuracy due to the high standard errors of genetic correlations used in its formation as was discussed previously. The restricted indices are:

$$I = -3.7(\text{Birth Weight}-25.6) + (\text{Weaning Weight}-190.1) \quad \ldots\ldots\ldots \; 24$$

$$I = -.004(\text{Birth Weight}-23.7) + (\text{Weaning Weight}-177.9) \quad \ldots\ldots\ldots \; 25$$

$$I = -2.24(\text{Birth Weight}-24.7) + (\text{Weaning Weight}-184.5) \quad \ldots\ldots\ldots \; 26$$

where indices 24, 25, and 26 apply to male calves, female calves, and combined sex selection, respectively.

Summary

Records of birth weight, weaning weight, and preweaning average daily gain were collected during the years 1965 to 1979 from an Angus herd at the Brooksville Beef Cattle Research Station, Brooksville, Florida. The main objective was to contruct an index that can increase weaning weight while restricting increases in birth weight to avoid increased calving difficulty. The selection indices developed were based on birth weight and weaning weight. The general indices and indices that restricted increases in birth weight were developed using data from male and female calves, separately and also from a combined sex data set. Predicted responses to selection using the indices developed were obtained. The phenotypic and genetic variances and covariances necessary to develop these indices were estimated from this data set and then compared with literature averages. The parameters obtained in this study were within the range of literature averages, and therefore, were considered appropriate for use in the construction of the indices.

Heritabilities, phenotypic, and genetic correlations were obtained in addition to the estimation of variance and covariance components. All estimates were obtained from paternal half sib analyses. Heritabilities of birth weight within the males, females, and the combined sex group of calves were found to be .339±.128, .369±.150, and .257±.079. Heritabilities of weaning weight in males, females, and in the combined sex group were estimated to be .537±.142, .201±.138, and .361±.088, respectively. Heritabilities of preweaning average daily gain within these three groups were found to be .496±.140, .147±.134, and .346±.087. Phenotypic correlations between birth weight and weaning weight within these three sex groups were found to be .481±.172, .481±.406, and .423±.159. Phenotypic correlations between birth weight and preweaning average daily gain in three sex groups were .231±.218, .305±.307, and .252±.184, respectively. Phenotypic correlations between weaning weight and preweaning average daily gain within the three sex groups were found to be .977±.108, .975±.867, and .976±.260. Genetic correlations between birth weight and weaning weight obtained within males, females, and the combined sex group were .546±.155, .588±.236, and .357±.169, respectively. Genetic correlations between birth weight and preweaning average daily gain in three sex groups were .399$\pm$.195, .298$\pm$.392, and .173$\pm$.191. Genetic correlations between weaning weight and preweaning average daily gain in the corresponding three sex groups were found to be .975$\pm$.109, .929$\pm$.139, and .971$\pm$.110, respectively.

Unrestricted selection indices for males, females, and the combined sex group, respectively, were found to be: I = .094(BW - 25.6) + (WW - 190.1); I = .501(BW - 23.7) + (WW - 177.9); and I = -.877(BW - 24.7) + (WW - 184.5). The indices restricted on birth weight in the three corresponding groups were: I = -3.7(BW - 25.6) + (WW - 190.1); I = -.004(BW - 23.7) + (WW - 177.9); and I = -2.24(BW - 24.7) + (WW - 184.5), respectively. Predicted response to selection based on the unrestricted indices for birth weight and weaning weight within males, females, and the combined sex group were found to be .764 and 9.360, .134 and 1.654, and .195 and 5.353 kg per generation. In standard measures of these responses were .200 and.373, .037 and .071, and .051 and .213 σ_p, respectively. The predicted responses based on the restricted indices were lower than those obtained from unrestricted ones. The corresponding predicted responses for weaning weight in the three sex groups were found to be 6.800, .529, and 5.110 kg per generation. Standard measures of these responses were .273, .002, and .200 phenotypic standard deviation unit. The predicted responses of weaning weight obtained from selection using restricted selection indices were found to be 73, 32, and 95% of those responses using the unrestricted indices within males, females, and combined sexes group, respectively.

STUDY II:
GENETIC AND PHENOTYPIC TRENDS

Introduction

Selection of bulls in many beef herds in Florida has been partially based on weights at 18 months of age and postweaning gain. Selection in the heifers is primarily based on reproductive efficiency with some emphasis on weights and gains. It is important to be able to evaluate, after selection has been practiced for some time, the trend in genetic improvement as compared to that due to environmental changes. If the genetic trend is positive throughout the period of the study, it means that selection has been successful. Improvement of a trait over time may also be caused by improvement in feeding and management (positive environmental trend). In such a case, these inputs must be continuously increased to maintain a positive environmental trend. The evaluation of genetic trend is therefore important and useful after selection has been practiced in a herd for some period. There have been many reports of genetic, phenotypic, and environmental trends in beef cattle in other parts of the United States (Petty and Cartwright, 1960; Dickerson, 1969; Alenda, 1980; Martin and Alenda, 1982; Wilkes, 1983; Zollinger and Nielsen, 1984). Evaluation of trends in Florida beef herds, however, have seldom been reported. Stewart (1974) and Beltran (1978) estimated genetic and phenotypic trends in beef herds raised in Florida during the years 1959 to 1975. However, neither genetic group nor relationships among animals were used in the trend analyses of these two studies. This study, therefore, has as its main objective the estimation of phenotypic and genetic trends in an Angus herd using an analysis based on genetic group as recommended by the Beef Improvement Federation (BIF, 1986).

Materials and Methods

Source and Description of Data

The data for this study were collected from the Angus herd at the USDA Beef Cattle Research Station (Subtropical Agricultural Research Station), Brooksville, Florida. The data consisted of birth weight, weaning weight, and preweaning average daily gain. Details about history of the herd and management are as explained in study I. Replacement bulls were selected based on 18 month weight and postweaning gain with some attention given to structural soundness and the productivity of their dam. At 18 months of age, approximately 15% of the heifers were culled due to poor rate of gain or unsoundness. The remaining 85% were exposed to bulls for about 60 days at about 2 years of age and delivered their first calves at 3 years of age. Females failing to conceive were culled. Approximately 5-15% of the cow herd was culled each year because of low production, depending on the number of pregnant cows and heifers, making the total proportion of females culled each year about 25%.

The data contained records of calves whose birth years were between 1967 and 1976. A restriction was imposed that each sire was required to have at least three offspring to be included. Table 22 shows the distribution of progeny by sire and year of calf birth.

TABLE 22. DISTRIBUTION OF PROGENY WITHIN SIRE AND YEAR OF CALF BIRTH

Sire	Year of calf birth									
	70	71	72	73	74	75	76	77	78	79
70043	12	3								
70219	13	5								
70166		5								
80039		7	9							
80055		6	11							
80162		8								
90023			14	17						
90056			8	10						
90177			8	12	12					
90189			12							
00043				14						
00061				14	7					
00142					4					
10033					13	12	13			
10122					4					
10141					11					
10172					10	13				
10177								12		
20533					6					
20004						6				
20021						17				
20026						10	5			
20046						6				
20104						7				
20127						14				
11172							6			
30005							9	12		
30010							8	10		
30014							4			
30015							11	7		
30067							15			
40018								12		
40035								20		
40045								13		
50025									18	16
50029									20	16
50175									17	14
50190									20	
60017										12
60053										18
40 sires	25	34	62	67	67	85	71	88	75	76

There were 40 sires and 118 dams used during the years 1970 to 1979. Sires used through artificial insemination were deleted from the data set, hence only sires born within the herd were used for the evaluation of trends. On the average, a sire was used only one and a half years with a range of one to three years (table 22). More than half of the sires were used only one year. Table 23 presents the distribution of progeny by sire and year of sire birth. As presented in table 24, approximately four sires were used within each year of sire birth. The number of progeny per sire averaged 16.

Means and standard deviations of the three preweaning growth traits for progeny of each sire are presented in table 25. Birth weights ranged from 21.5 kg for calves from sire 70219 to 30.7 kg for calves from sire 00142 with the herd mean being 24.6 kg. Weaning weight and preweaning average daily gain were 175.5 and .689 kg, respectively. Sire 60053 produced calves with the highest average weaning weight of 199.6 kg, while the lowest average weaning weight was produced by sire 20533. For preweaning average daily gain, an average of .774 kg was observed in calves born from sire 00142 with an overall average of .554 kg.

Model Description and Statistical Analyses

Three mathematical models were used to evaluate trends in birth weight, weaning weight, and preweaning average daily gain. The first two were utilized for estimation of genetic trends based on sire and dam contributions while the third dealt with phenotypic trend analyses. All models used in this study make the assumptions that no relationships existed among sires or among dams or between sires and

TABLE 23. DISTRIBUTION OF PROGENY WITHIN SIRE AND YEAR OF SIRE BIRTH

Sire	Year of sire birth									
	67	68	69	70	71	72	73	74	75	76
70043	15									
70166	5									
70219	18									
80039		16								
80055		17								
80162		8								
90023			31							
90056			18							
90177			20							
90189			12							
00043				14						
00061				21						
00142				4						
10033					38					
10122					4					
10141					11					
10172					23					
10177					12					
11172					6					
20004						6				
20021						17				
20026						15				
20046						6				
20104						7				
20127						14				
20533						6				
30005							21			
30010							18			
30014							4			
30015							18			
30067							15			
40018								26		
40035								20		
40045								13		
50025									34	
50029									36	
50175									31	
50190									20	
60017										12
60053										18
Total/year	38	41	81	39	94	71	76	59	121	30

TABLE 24. NUMBER OF SIRES USED AND NUMBER OF PROGENY FROM SIRES WITHIN YEAR OF SIRE BIRTH

Year of sire birth	Number of sires used	Number of progeny	Average number of progeny per sire
1967	3	38	13
1968	3	41	14
1969	4	81	20
1970	3	39	13
1971	6	94	16
1972	7	71	10
1973	5	76	15
1974	3	59	19
1975	4	121	30
1976	2	30	15
Mean	4.2±1.4[a]	65.0±29.1	16.5±5.5

[a] Mean±Standard deviation.

TABLE 25. PROGENY MEANS AND STANDARD DEVIATIONS FOR BIRTH WEIGHT WEANING WEIGHT, AND PREWEANING AVERAGE DAILY GAIN BY SIRE[a]

Sire	Number of progeny	Birth Weight		Weaning Weight		PADG[b]	
		Mean	SD[c]	Mean	SD	Mean	SD
00043	14	22.2	2.7	180.4	23.3	.679	.074
00061	21	23.6	2.9	186.4	21.7	.711	.090
00142	4	30.7	5.8	154.8	16.2	.774	.065
10033	38	25.9	4.3	184.9	22.6	.706	.097
10122	4	26.0	2.0	131.8	7.5	.624	.062
10141	11	23.2	3.5	183.5	25.7	.709	.088
10172	23	26.1	4.0	177.7	15.9	.695	.078
10177	12	25.0	2.7	181.1	23.5	.720	.095
11172	6	22.9	4.0	186.6	19.7	.689	.060
20021	17	25.7	2.3	166.3	23.9	.572	.098
20026	15	26.7	3.4	183.6	22.1	.699	.073
20046	6	26.6	4.0	177.5	16.4	.611	.065
20104	7	25.4	3.1	176.9	19.9	.604	.075
20127	14	25.4	2.6	184.0	22.7	.715	.071
20533	6	25.7	3.6	110.7	25.1	.558	.101
30005	21	24.2	4.5	194.2	24.8	.731	.096
30010	18	25.9	3.7	196.9	16.8	.740	.069
30014	4	25.3	2.5	177.4	27.4	.663	.056
30015	18	26.2	4.9	176.9	27.3	.689	.093
30067	15	24.8	2.9	171.2	28.6	.684	.107
40018	26	26.3	4.0	199.5	19.5	.737	.066
40035	20	25.1	3.7	185.6	14.6	.721	.080
40045	13	24.7	6.1	193.7	16.3	.701	.063
50025	34	25.9	3.9	197.9	21.3	.761	.073
50029	36	26.1	5.6	193.4	21.5	.755	.082
50175	31	26.2	4.4	193.4	21.2	.749	.080
50190	20	25.9	3.6	184.6	22.0	.722	.059
60017	12	24.1	3.3	198.9	19.8	.771	.098
60053	18	22.7	3.0	199.6	19.2	.760	.067
70043	15	24.0	2.9	179.7	13.4	.673	.068
70166	5	22.9	4.0	168.9	12.1	.703	.044
70219	18	21.5	1.9	171.8	23.7	.656	.083
80039	16	23.3	3.6	167.0	15.4	.682	.094
80055	17	24.3	2.1	172.6	25.9	.692	.120
80162	8	22.7	2.5	167.8	26.8	.723	.141
90023	31	22.4	2.0	178.7	22.9	.680	.085
90056	18	21.8	2.3	173.9	14.8	.644	.066
90177	20	24.2	2.4	181.6	28.1	.695	.086
90189	12	22.4	2.6	172.5	21.0	.645	.080
Average		24.6	2.7	175.5	21.7	.689	.055

[a] In kilogram.

[b] Preweaning average daily gain.

[c] Standard deviation.

dams. These assumptions were not true, but were made so that a statistical package (Harvey, 1977) could be used. Initially, full models containing both fixed and random effects were analyzed to determine the importance of interaction effects. The analyses revealed no interaction effects, therefore, models without interactions were used. Details of the final models can be explained based on the following equations,

$$Y_{ijklm} = Mu_i + SY_{ij} + S(SY)_{ijk} + F_l + e_{ijklm} \quad \text{.................} \quad 27$$

$$Y_{ipqln} = Mu_i + DY_{ip} + D(DY)_{ipq} + F_l + e_{ipqln} \quad \text{.................} \quad 28$$

$$Y_{idf} = Mu_i + F_d + e_{idf} \quad \text{....................} \quad 29$$

where Y_{ijklm} = observation on the jklmth experimental unit on the ith trait, i = 1, 2, 3 for birth weight, weaning weight, and preweaning average daily gain,

Y_{ipqln} = observation on the pqlnth experimental unit on the ith trait,

Y_{idf} = observation on the dfth experimental unit on the ith trait,

Mu_i = overall mean (fixed) of trait i,

SY_{ij} = effect of the jth year of sire birth (fixed) on the ith trait,

DY_{ip} = effect of the pth year of dam birth (fixed) on the ith trait,

$S(SY)_{ijk}$ = effect of the kth sire born within the jth year on the ith trait. S_k is assumed NID $(0, \sigma^2_{S(i)})$,

$D(DY)_{ipq}$ = effect of the q^{th} dam born within the p^{th} year, on the i^{th} trait. D_q is assumed NID $(0, \sigma^2_{D(i)})$,

F_1 = a set of fixed effects due to sex of calf, age of dam, and age of calf at weaning (fit only in the models for weaning weight and preweaning average daily gain),

F_d = a set of fixed effects due to sex of calf, age of dam, age of calf at weaning (fit only in the models for weaning weight and preweaning average daily gain), and year of calf birth,

e_{ijklm} = the random error, assumed NID $(0, \sigma^2_{e1})$,

e_{ipqln} = the random error, assumed NID $(0, \sigma^2_{e2})$, and

e_{idf} = the randomd error, assumed NID $(0, \sigma^2_{e3})$.

The correct procedure is to fit sire and dam in the same model together with their relationships in order to best obtain genetic trend. However, if this procedure is not used, use of genetic groups can be utilized as an alternative procedure to evaluate genetic trend (BIF, 1986). In this study, genetic groups were used in the evaluation of genetic trends. Year of sire birth and year of dam birth were defined as the genetic groups of sire and dam.

To fit the set of random effects into the set of fixed effects in Harvey's "maximum likelihood" procedure, LSML76 requires that the intra-class correlation be given. We need to know the variances due to sire, dam, and error. The variances used in this study were obtained from the results of variance estimation in study I. It is important to point out that the intra-class correlation for sire (equation 27) and dam (equation 28) models are different. Under the sire model, the intra-class correlation equals σ^2_S / σ^2_T, which equals $h^2/4$. The intra-class correlations for birth weight, weaning weight, and preweaning average daily gain were .075, .088, and .088, respectively. The intra-class correlations for dam are computed with a repeatability model. This is because records obtained from a dam over time are repeated measures which are influenced, in addition to direct additive genetic effects, by maternal and permanent environmental effects of the dam. A repeatability of .40 was given to all three preweaning traits for the dam model. The definition and assumption of sire model and dam model are described as follows.

Sire model

The year of sire birth solutions contain not only the average transmitting ability of sires that belong to their genetic groups, but also additional effects. Confounded with sire genetic group are a part of the dams' transmitting ability, the dam's direct maternal effects and permanent environmental effects. Transmitting ability is the sire's effect on offspring performance measured as the deviation from the population mean. Transmitting ability is sometimes called expected progeny difference (EPD) which equals one-half of the breeding value of the parent. The term, direct maternal effects, are defined as those maternal effects that an individual inherited from its dam. The permanent environmental effects are also defined as environmental effects on dam that are the same throughout her lifetime. It is not known how much these additional effects contribute to the total effects of sires' genetic groups.

Dam model

The genetic group of dam is defined as the year of dam birth. The contributions of dams to the total genetic improvement of the herd contains the dam's transmitting ability which contains the sires' genetic trend because the dams are daughters of the sires in this study.

Estimation of phenotypic trend

Phenotypic trend was estimated from equation 29. To estimate phenotypic trend, the best linear unbiased estimates of year of calf birth were obtained from the output of LSML76 under model type (MTY) 01 first. Model type 01 gives solutions for sets of fixed effects (other than Mu) such as discrete sets of cross-classified effects, interactions of discrete sets of effects, average or pooled partial regressions for continuous independent variables and individual class regressions for continuous independent variables. It can handle models with heterogeneous error variance. The second and final step of the analysis employed a weighted regression method as outlined by Steel and Torrie (1980) and Montgomery and Peck (1982). By regressing the year of calf birth solutions on year using PROC GLM with the WEIGHT statement as outlined by Freund and Littell (1981), the phenotypic change per year and its standard error were obtained. The weight factor assigned for the WEIGHT statement was the number of observations corresponding to the year of calf birth solutions. This is because number of observations is inversely proportional to the variance of the corresponding year of calf birth solutions.

Genetic trend based on sire contribution

Genetic trend under the sire model was estimated by regressing the year of sire birth solutions (obtained from the output from the analysis using Harvey's MTY 03 with absorption code NAB 03 on year of sire birth. Model type 03 handles the analysis involving a set of fixed effects and a set of random nested effects. Interactions of random and fixed effects are assumed to be zero. The estimator and its standard error were the same as those obtained from the ordinary least squares method. The PROC REG from the statistical analysis system (SAS, 1982) was employed to obtain these estimates.

Genetic trend based on dam contribution

Genetic trend under the dam model was evaluated in the same manner as those methods described in the sire model except that year of dam birth was used instead of the year of sire birth.

Results and Discussion

In the present study, three types of trends were analyzed. They are phenotypic trend, genetic trend due to sire contribution, and genetic trend due to dam contribution. Results are presented as follows:

Phenotypic Trends

Year of calf birth solutions were obtained from solving model 29, and they are shown in table 26 for birth weight, weaning weight, and preweaning average daily gain. Phenotypic trends for these three traits obtained from a weighted regression method (table 27) were found

TABLE 26. SOLUTIONS FOR BIRTH WEIGHT, WEANING WEIGHT, AND PREWEANING AVERAGE DAILY GAIN BY YEAR OF CALF BIRTH FROM FIXED EFFECT MODEL 29[a]

Year	Birth weight		Weaning weight		Preweaning average daily gain	
	Solutions	SE	Solutions	SE	Solutions	SE
1970	−.663	.303	−1.952	3.884	−.0032	.0069
1971	−.461	.258	−5.582	3.412	.0064	.0061
1972	−.769	.199	−3.288	2.542	−.0136	.0045
1973	−.847	.188	−1.925	2.415	−.0105	.0043
1974	.624	.187	6.068	2.526	.0051	.0045
1975	.655	.167	−4.914	2.146	−.0275	.0039
1976	.059	.180	−0.889	2.289	.0059	.0041
1977	.572	.178	2.549	2.288	.0019	.0041
1978	1.413	.168	3.379	2.139	.0157	.0038
1979	−.463	.178	6.553	2.279	.0251	.0040

[a] In kilogram.

to be .165±.080, .955±.413, and .006±.004 kg per year, respectively. Profiles of phenotypic trends are presented in figures 1 through 3 by ploting year of calf birth solutions (obtained from the fixed effect model 29) against year. The constants varied considerably from year to year for all three traits. A range of -.847 to 1.413 kg was found for birth weight whereas ranges of -.582 to 6.553 kg and -.003 to .025 kg were observed for weaning weight and preweaning average daily gain, respectively.

The phenotypic trend for birth weight in this study was higher than the estimates reported by Petty and Cartwright (1960), Koch et al. (1974), and Beltran (1978). However, Flower et al. (1964) and Kennedy (1984) reported trends that agree with those found in our study.

The phenotypic trend for weaning weight found in this study agrees well with estimates reported by many authors (Flower et al., 1964; Alenda, 1980; Martin and Alenda, 1982; and Wilkes, 1983). Lower estimates were found by Zabel (1973), Vanmiddlesworth (1980), and Tumwasorn et al. (1986). The phenotypic trend for weaning weight increased more consistently than birth weight, as is illustrated in figure 2. The only decreasing periods found in the weaning weight trend profile were during the years 1970 to 1971 and 1974 to 1975. The phenotypic trend for preweaning average daily gain obtained from this analysis was lower than most other studies that have been reported (Flower et al., 1964; Chapman et al., 1968; Kwakalor et al., 1976). Nevertheless, Zabel (1973) and Buchanan (1980) obtained estimates that agree well with the present study. Figure 3 shows the profile of the trend for preweaning average daily gain obtained by ploting year against year of calf birth solutions for PADG obtained from the fixed

TABLE 27. PHENOTYPIC CHANGES PER YEAR FOR BIRTH WEIGHT, WEANING WEIGHT, AND PREWEANING AVERAGE DAILY GAIN

Trait	Phenotypic change per year		p value
	Mean (kg)	S.E.[a]	
Birth weight	.1546	.0787	.0729
Weaning weight	.9548	.4123	.0493
Preweaning average daily gain	.0055	.0042	.2300

[a] Standard error.

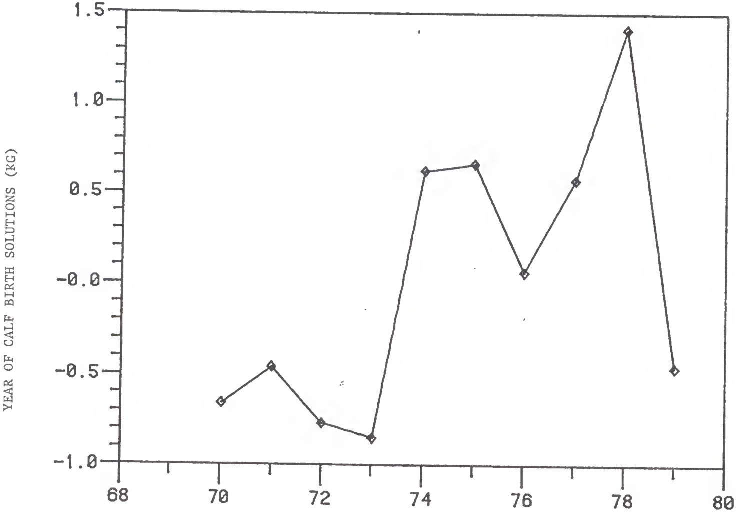

FIGURE 1. PHENOTYPIC TREND OF BIRTH WEIGHT BASED ON YEAR OF CALF BIRTH SOLUTIONS OBTAINED FROM FIXED EFFECT MODEL 29

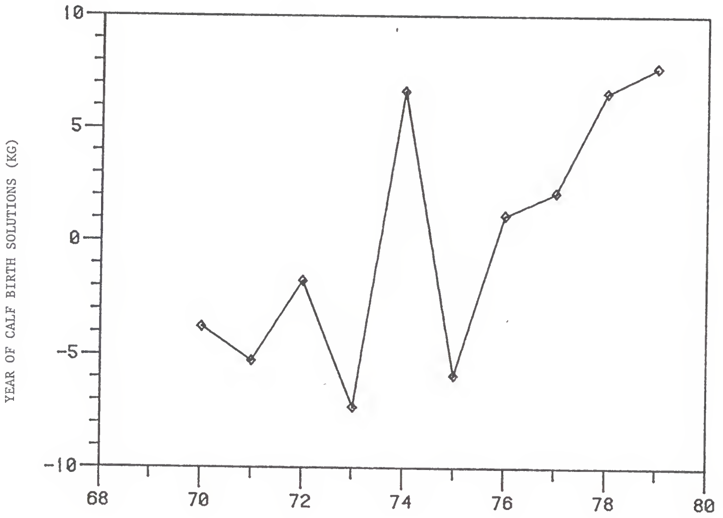

FIGURE 2. PHENOTYPIC TREND OF WEANING WEIGHT BASED ON YEAR OF CALF BIRTH SOLUTIONS OBTAINED FROM FIXED EFFECT MODEL 29

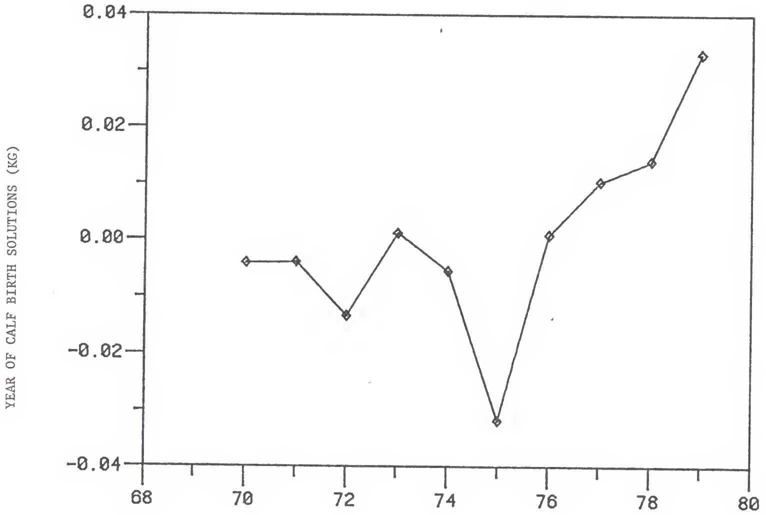

FIGURE 3. PHENOTYPIC TREND OF PREWEANING AVERAGE DAILY GAIN BASED ON YEAR OF CALF BIRTH SOLUTIONS OBTAINED FROM FIXED EFFECT MODEL 29

effect model 29.

Genetic Trends

The genetic trends for birth weight, weaning weight, and preweaning average daily gain were estimated based on sire and dam contributions. The analyses of variance for factors affecting these respective three traits are shown in appendix tables 41 through 46 according to the models used.

Genetic trends based on sire contribution

The genetic trend for birth weight based on sire contribution was found to be .112 kg per year with a standard error of .049 kg per year (table 28). The genetic trend for birth weight is shown in a profile trend in figure 4. Solutions for year of sire birth, which are shown in table 28, ranged from -.596 kg in the year 1970 to .724 kg for the year 1978. The estimate obtained from this study agrees well with those reported by Chapman et al. (1968) and Vanmiddlesworth (1980). In general, most estimates of genetic trend in birth weight were found to be higher than the result obtained from this study (Kennedy et al., 1977; Martin and Alenda, 1982; and Kress et al., 1986).

Equation 27 was used in estimating genetic trend due to sire contribution. The genetic trend for weaning weight was found to be 1.207±.280 kg per year based on regressing the year of sire birth solutions on years. The profile of genetic trend for weaning weight is illustrated in figure 5 by ploting year of sire birth solutions against years. The genetic trend for weaning weight found by other researchers were in the same range as that obtained in this study (Flower et al.,

TABLE 28. GENETIC CHANGES PER YEAR BASED ON SIRE CONTRIBUTION FOR BIRTH WEIGHT, WEANING WEIGHT, AND PREWEANING AVERAGE DAILY GAIN

Trait	Genetic change per year		p value
	Mean (kg)	S.E.[a]	
Birth weight	.1124	.0491	.0511
Weaning weight	1.2074	.2799	.0026
Preweaning average daily gain	.0058	.0017	.0097

[a] Standard error.

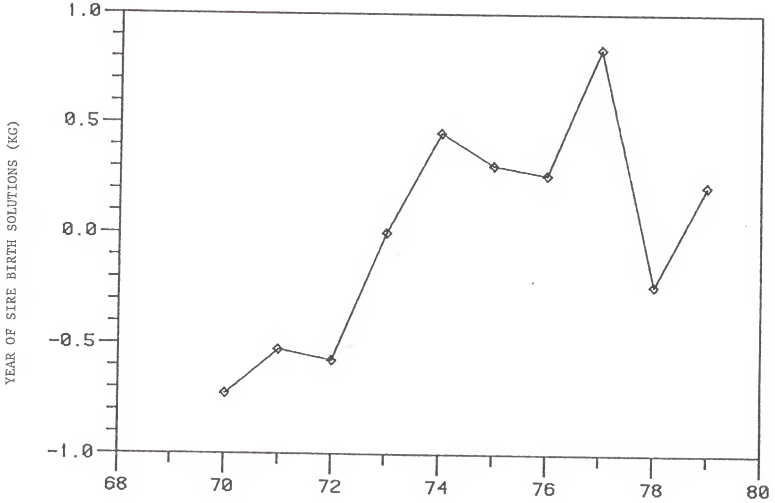

FIGURE 4. GENETIC TREND OF BIRTH WEIGHT BASED ON SIRE CONTRIBUTION FROM MIXED MODEL 27

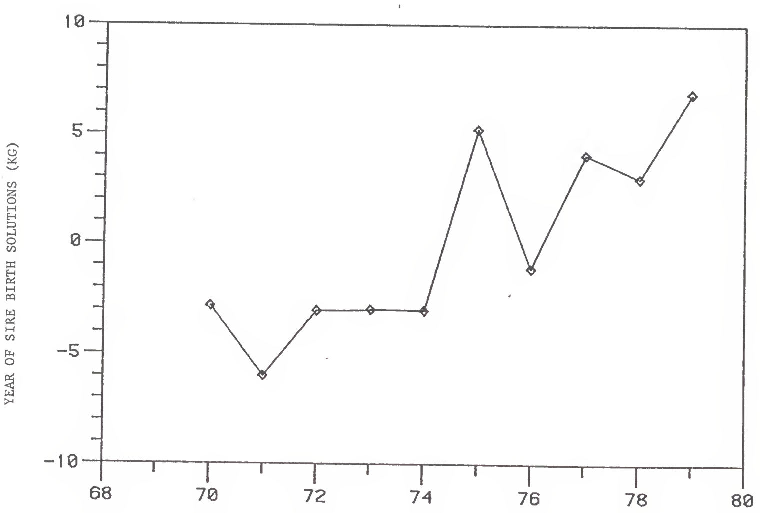

FIGURE 5. GENETIC TREND OF WEANING WEIGHT BASED ON SIRE CONTRIBUTION FROM MIXED MODEL 27

1964; Alenda, 1980; Martin and Alenda, 1982; Wilkes, 1983). Negative estimates were found by Zabel (1973) and Buchanan (1980).

Preweaning average daily gain was evaluated using the mixed model presented as equation 27. The genetic trend for preweaning average daily gain was found to be .006±.002 kg per year (table 27). Tumwasorn et al. (1986) obtained an estimate of .004 kg per year for genetic trend of preweaning average daily gain estimated from the same herd but during a different period of time. The estimate obtained from this study agrees with the reports of Nwakalor et al. (1976) and Alenda (1980). The profile of the genetic trend of preweaning average daily gain obtained by ploting the year of sire birth constants against year is shown in figure 6. Solutions for year of sire birth, obtained from solving equation 27, ranged between -.0264 in 1975 to .0512 in the final year as shown in table 29. An increasing trend was found in the the last period of the study, from 1975 to 1979, however a negative trend was found during the years 1970 to 1975.

Genetic trends based on dam contribution

Genetic trend for birth weight based on dam contribution was found to be .112±.049 kg per year (table 30). The profile for genetic trend of birth weight based on dam contribution is shown in figure 7. Table 30 shows the solutions for year of dam birth obtained from solutions of mixed model equation 28. The solutions for year of dam birth ranged from -.788 kg in 1972 to .724 kg in 1978. Increasing trends were observed sporadically over the course of the study, 1970-1971, 1973 to 1975 and 1976 to 1978. The genetic contribution of the dam in the present study was less than that of the sire. This finding is in

TABLE 29. SOLUTIONS FOR YEAR OF SIRE BIRTH FOR PREWEANING GROWTH TRAITS BASED ON MIXED MODEL 27

Year	Birth weight		Weaning weight		Preweaning average daily gain	
	Solutions[a]	SE[b]	Solutions	SE	Solutions	SE
1970	−.596	.366	−2.850	4.546	−.0073	.0038
1971	−.545	.352	−5.997	4.405	−.0196	.0063
1972	−.788	.289	−3.046	3.627	−.0109	.0049
1973	−.028	.366	−2.996	4.559	−.0146	.0046
1974	.246	.267	−3.029	3.325	−.0099	.0042
1975	.553	.264	5.215	3.264	−.0264	.0043
1976	.358	.279	−1.136	3.476	.0068	.0043
1977	.447	.327	4.026	4.108	.0099	.0049
1978	.724	.277	2.953	3.483	.0209	.0054
1979	−.371	.412	6.859	5.136	.0512	.0097

[a] In kilogram.
[b] Standard error.

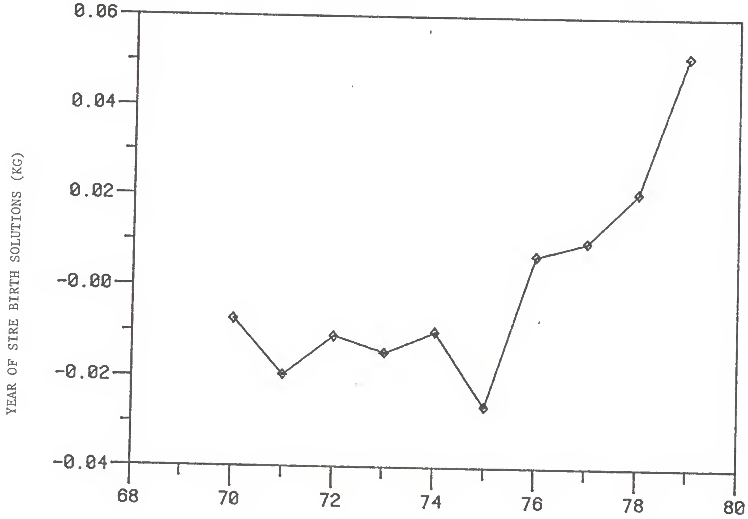

FIGURE 6. GENETIC TREND OF PREWEANING AVERAGE DAILY GAIN BASED ON SIRE CONTRIBUTION FROM MIXED MODEL 27

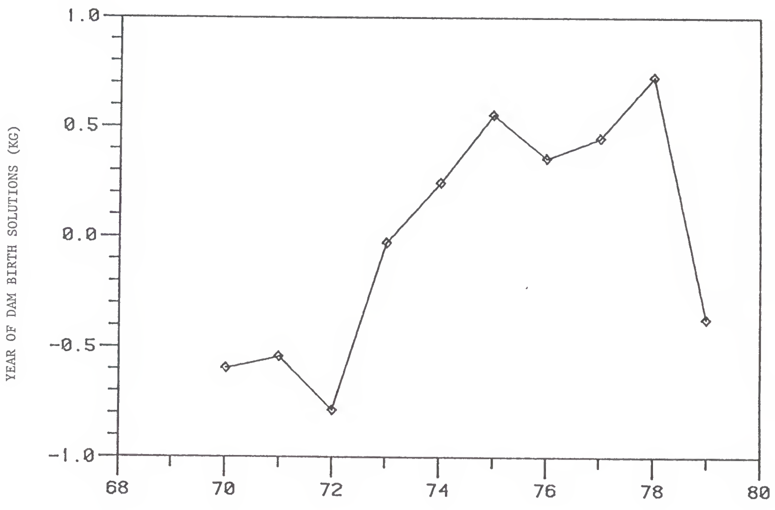

FIGURE 7. GENETIC TREND OF BIRTH WEIGHT BASED ON DAM CONTRIBUTION FROM MIXED MODEL 28

agreement with many reports (Gaskins, 1974; Chenette et al., 1982; Zollinger and Nielsen, 1984).

The genetic trend for weaning weight based on dam contribution was estimated to be 1.323±.462 kg per year as shown in table 30. The trend profile based on dam contribution for weaning weight is illustrated by ploting year of dam birth solutions on years as shown in figure 8. Solutions for year of dam birth obtained from mixed model equation 28 are reported in table 30. The range of the constants was from -5.997 kg in 1971 to 6.859 kg in the final year. An increasing trend was found during the years 1975 to 1979 or the second half of the period of the study, whereas the trend fluctuated during the period of 1970 to 1975. The estimate obtained from the present study was in the range reported by Chapman et al. (1968) and Nwakalor et al. (1976). Higher estimates were found by other authors (Flower et al., 1964; Alenda, 1980; and Wilkes, 1983).

In the present study, the genetic trend for preweaning average daily gain based on dam contribution was .003±.002 kg per year. The profile for genetic trend due to dam contribution for preweaning average daily gain is illustrated in figure 9. Table 31 shows the solutions for year of dam birth obtained from solving mixed model equation 28. The range of these solutions was between -.0264 kg in 1975 and .0512 kg in the final year (1979). A period of fluctuation was found during the years 1970 to 1975 which was followed by an increasing trend until the end of the study period. Buchanan (1980) and Zollinger and Nielsen (1984) reported similar estimates to those of the present study, while higher estimates were found by Flower et al. (1964) and Martin and Alenda (1982).

TABLE 30. GENETIC CHANGES PER YEAR FOR PREWEANING GROWTH TRAITS BASED ON DAM CONTRIBUTION

Trait	Genetic change per year		p value
	Mean (kg)	S.E.[a]	
Birth weight	.1102	.0444	.0377
Weaning weight	1.3232	.4622	.0211
Preweaning average daily gain	.0033	.0016	.0728

[a] Standard error.

TABLE 31. SOLUTIONS FOR YEAR OF DAM BIRTH FOR PREWEANING GROWTH TRAITS BASED ON MIXED MODEL 28

Year	Birth weight		Weaning weight		Preweaning average daily gain	
	Solutions[a]	SE[b]	Solutions	SE	Solutions	SE
1970	−.727	.175	−3.782	2.121	−.0042	.0083
1971	−.528	.288	−5.291	3.489	−.0040	.0080
1972	−.574	.220	−1.774	2.669	−.0134	.0066
1973	−.001	.207	−7.314	2.532	.0011	.0083
1974	.451	.189	6.608	2.293	−.0056	.0060
1975	.304	.196	−5.925	2.366	−.0318	.0059
1976	.261	.195	1.130	2.352	.0008	.0063
1977	.836	.228	2.107	2.747	.0102	.0075
1978	−.237	.247	6.563	2.978	.0139	.0063
1979	.214	.445	7.678	5.332	.0329	.0093

[a] In kilogram.
[b] Standard error.

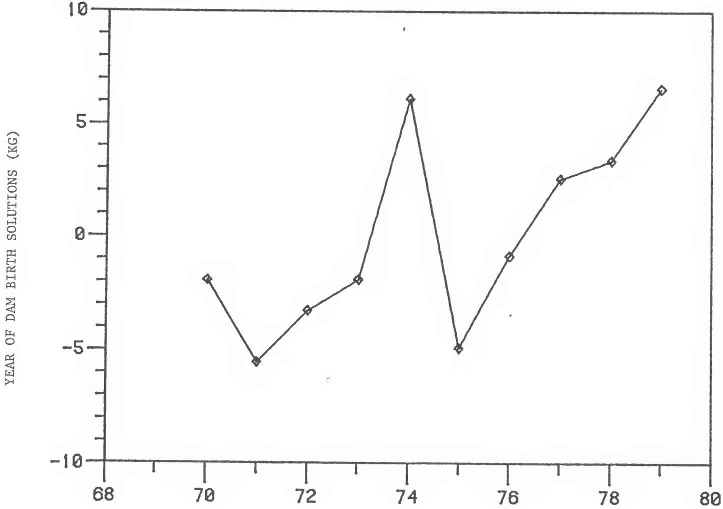

FIGURE 8. GENETIC TREND OF WEANING WEIGHT BASED ON DAM CONTRIBUTION FROM MIXED MODEL 28

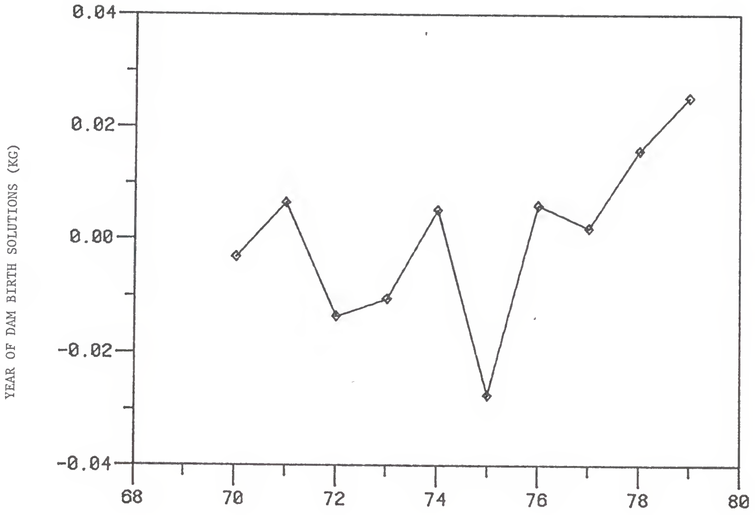

FIGURE 9. GENETIC TREND OF PREWEANING AVERAGE DAILY GAIN BASED ON DAM CONTRIBUTION FROM MIXED MODEL 28

In conclusion, it was found that for most of preweaning traits, except weaning weight, sire contributions to the improvement of the herd was higher than those of dam contributions. However, due to inability to completely separate sires' and dams' transmitting ability from the total improvement of the herd, only the approximate estimates were obtained. The genetic trends resulted from this study give us some guidelines concerning the response to this type of selection over this period of time. It is clear, based on these approximate trends that selection for increased growth has been effective.

Summary

Trend analyses in this study were obtained from the evaluation of calves born from 40 sires and 118 dams of the Angus breed. The data were collected during the years 1967 to 1976 from the Brooksville Beef Cattle Research Station, Brooksville, Florida. Birth weight, weaning weight and preweaning average daily gain were the traits of interest. The fixed effects included in the models used to estimate trends were calf sex, age of dam, year of sire birth, year of calf birth, year of dam birth, and age of calf (for weaning weight and preweaning average daily gain). Random effects were sire and dam effects which were fitted separately in the sire and dam models. The genetic group for the sire model was defined as the year of sire birth whereas year of dam birth was the genetic group for the dam model. Phenotypic trends were estimated by regressing the constants for year of calf birth (obtained from the solutions of the fixed effects model) on time by weighted regression. Genetic trends based on sire and dam contributions were estimated by regressing year of sire birth and year of dam birth solutions (obtained from the solutions of sire and dam models) on time by simple linear regression.

Phenotypic trends on birth weight, weaning weight, and preweaning average daily gain were found to be .155±.079, .955±.412, and .006±.004 kg per year, respectively. Genetic trends on these three traits based on sire contributions were .112±.049, 1.207±.280, and .006±.002 kg per year as compared to estimates of .110±.044, 1.323±.462, and .003±.002 kg per year based on dam contributions. Since sires and dams were simultaneously selected within the same herd for the same time interval, it was unable to separate the confounding effects of sires and dams using the present models. The genetic trends obtained from this study were, therefore, considered to be approximate estimates.

SUMMARY AND CONCLUSIONS

Preweaning records over a 15-year period (1965 to 1979) were collected from an Angus herd at the Brooksville Beef Cattle Research Station (Subtropical Agricultural Research Station), Brooksville, Florida. The principal objectives of the study were to evaluate phenotypic and genetic trends and to develop selection indices based on birth weight (BW) and weaning weight (WW).

A fixed effect model was used to estimate the phenotypic trends using the weighted regression method. Two different mixed models were used to estimate genetic changes based on sire and dam contributions. Random effects were sire and dam effects, whereas fixed effects were year of calf birth, year of sire birth, year of dam birth, age of dam, and age of calf (for weaning weight and preweaning average daily gain analyses). Year of sire birth was considered to provide genetic grouping based on sire contributions whereas year of dam birth was the genetic grouping on which dam contribution was based. By regressing year of calf birth solutions on time, estimates of phenotypic changes were obtained. Genetic trends based on sire contributions were obtained by regressing year of sire birth solutions on time. In the same manner, genetic trends based on dam contributions were estimated by regressing year of dam birth solutions on time. Both genetic trends for sire and dam contributions were considered to be approximate estimates due to the inability to separate the confounding effects of sires and dams from both the sire and dam models. Phenotypic trends on birth weight, weaning weight, and preweaning average daily gain were found to be .155±.079, .955±.412, and .006±.004 kg per year. Genetic trends for these three traits were found to be positive for both sire and dam contributions. Genetic trends per year for birth weight, weaning weight, and preweaning average daily gain were reported to be .112±.049, 1.207±.280, and .006±.002 kg per year as compared to the trends of .110±.044, 1.323±.462, and .003±.002 kg per year for dam contributions. Genetic trends obtained in this study were all lower than those reported by Stewart (1974) from the same herd but covering a different period. One explanation for the lower trends was the inclusion of genetic groups in the models in this study. Even though only approximate estimates of trends were obtained, selection of bulls based on 20 month weight appeared to have been effective in simultaneously increasing birth weight, weaning weight, and preweaning average daily gain.

Selection indices were developed based on birth weight and weaning weight. The analyses were made within males, within females, and on a combined sexes basis. Contrary to many reports on the development of selection indices, the phenotypic and genetic variances and covariances were estimated from the data collected on this herd. These estimates were found to be within the range of literature averages, and therefore, were considered appropriate to use in the construction of selection indices. Unrestricted selection indices developed from the male, female, and combined sex data sets were: I = .094(BW − 25.6) + (WW − 190.1); I = .501(BW − 23.7) + (WW − 177.9); and I = −.877(BW −

24.7) + (WW - 184.5), respectively. Indices restricted on birth weight in these three respective sex groups were found to be: -3.7(BW - 25.6) + (WW - 190.1); -.004(BW - 23.7) + (WW - 23.7); and -2.24(BW - 24.7) + (WW - 184.5). The respective predicted responses to selection obtained from the restricted indices were found to be 72.6, 32.0, and 95.5% of those obtained from using unrestricted indices in the three groups. Due to the high standard errors of the genetic and phenotypic parameters from the female group analyses, selection indices for females were not as reliable as indices developed from males and from the combined sex data. The predicted responses per generation from selection using the unrestricted versus restricted indices within male calves were found to be .764 versus 0 kg for birth weight, and 9.360 versus 6.800 kg for weaning weight. These predicted responses in this study were based on the assumption that 5% of males and 80% of females would be selected. Responses to selection within females for the unrestricted and restricted indices were found to be .134 versus 0 kg, and 1.654 versus .529 kg per generation for BW and WW, respectively. The results of predicted response to selection obtained from the combined sex group represented the predicted response of the entire herd. These responses for birth weight and weaning weight, using unrestricted and restricted indices, were found to be .195 versus 0 kg, and 5.535 versus 5.110 kg per generation for BW and WW, respectively. In addition, because the predicted response in weaning weight from selection using selection indices that restrict birth weight was a substantial proportion of that resulting from use of the unrestricted indices (73 and 95% for male calves and combined sex group, respectively). Thus, selection indices restricted on birth weight should be quite useful in the future if allowing increases in weaning weights while avoiding increases in birth weights becomes necessary in this Angus herd. If such selection indices were to be widely used in Angus herds throughout Florida, it may be necessary to develop selection indices based on multi-herd information in order to obtain reliable predicted responses.

APPENDIX

TABLE 32. ANALYSIS OF VARIANCE FOR FACTORS AFFECTING BIRTH WEIGHT FOR VARIANCE COMPONENT ESTIMATION FROM MODEL 1 WITHIN MALE CALVES

Source of variation	df	Mean Square	p value
Sire	94	411.21	.0016
Year of calf birth	14	14.82	.6813
linear	1	640.98	.0080
quadratic	1	332.31	.0540
cubic	1	2194.29	<.0001
quartic	1	543.60	.0143
quintic	1	411.21	<.0001
residual	9	87.29	.0016
Age of dam	9	229.13	.0001
linear	1	595.76	.0012
quadratic	1	1038.21	<.0001
cubic	1	146.15	.1081
quartic	1	155.42	.0975
quintic	1	5.16	.7624
residual	4	30.37	.7077
Remainder	557	56.41	

TABLE 33. ANALYSIS OF VARIANCE FOR FACTORS AFFECTING BIRTH WEIGHT FOR VARIANCE COMPONENT ESTIMATION FROM MODEL 1 WITHIN FEMALE CALVES

Source of variation	df	Mean Square	p value
Sire	97	80.62	<.0001
Year of calf birth	14	289.89	.0001
linear	1	389.12	.0304
quadratic	1	747.03	.0030
cubic	1	83.84	.3104
quartic	1	1076.02	.0004
quintic	1	27.49	.5606
residual	9	192.78	.0172
Age of dam	9	66.64	.2751
linear	1	160.75	.0859
quadratic	1	101.76	.1715
cubic	1	41.56	.3819
quartic	1	79.72	.2260
quintic	1	41.71	.3810
residual	4	43.57	.5235
Remainder	450	54.24	

TABLE 34. ANALYSIS OF VARIANCE FOR FACTORS AFFECTING BIRTH WEIGHT FOR VARIANCE COMPONENT ESTIMATION FROM MODEL 1 WITHIN COMBINED SEXES OF CALVES

Source of variation	df	Mean Square	p value
Sire	99	97.94	<.0001
Year of calf birth	14	748.72	<.0001
linear	1	251.44	.1123
quadratic	1	1410.44	.0003
cubic	1	340.85	.0651
quartic	1	3123.96	<.0001
quintic	1	447.11	.0351
residual	9	545.36	<.0001
Sex of calf	1	5158.96	<.0001
Age of dam	9	219.99	.0001
linear	1	561.62	.0018
quadratic	1	1113.59	<.0001
cubic	1	27.87	.4842
quartic	1	185.66	.0712
quintic	1	68.88	.2715
residual	4	5.57	.9832
Remainder	1122	56.90	

TABLE 35. ANALYSIS OF VARIANCE FOR FACTORS AFFECTING WEANING WEIGHT FOR VARIANCE COMPONENT ESTIMATION FROM MODEL 1 WITHIN MALE CALVES

Source of variation	df	Mean Square	p value
Sire	94	2941.57	<.0001
Year of calf birth	14	16519.94	<.0001
linear	1	17906.14	.0154
quardratic	1	13372.37	.0356
cubic	1	894.88	.5826
quartic	1	843.88	.5935
quintic	1	27687.92	.0028
residual	9	18952.66	<.0001
Age of dam	9	16077.17	<.0001
linear	1	42698.44	<.0001
quardratic	1	89493.26	<.0001
cubic	1	83.18	.8164
quartic	1	7762.62	.0252
quintic	1	19.13	.9113
residual	4	1159.47	.5569
Age of calf linear	1	75.69	.8247
quardratic	1	801.93	.4711
cubic	1	1546.38	.3170
Remainder	554	1541.61	

TABLE 36. ANALYSIS OF VARIANCE FOR FACTORS AFFECTING WEANING WEIGHT FOR VARIANCE COMPONENT ESTIMATION FROM MODEL 1 WITHIN FEMALE CALVES

Source of variation	df	Mean Square	p value
Sire	97	1880.74	<.0001
Year of calf birth	14	15141.63	<.0001
linear	1	36500.31	<.0001
quadratic	1	114132.02	<.0001
cubic	1	3617.52	.1687
quartic	1	557.67	.5873
quintic	1	1583.39	.3611
residual	9	6176.87	.0016
Age of dam	9	6470.20	<.0001
linear	1	28400.83	<.0001
quadratic	1	21866.03	.0001
cubic	1	1157.83	.3538
quartic	1	2015.31	.2214
quintic	1	916.15	.4095
residual	4	968.92	.5780
Age of calf linear	1	1615.21	.2736
quadratic	1	2592.69	.1656
cubic	1	2352.72	.1204
Remainder	447	1344.04	

TABLE 37. ANALYSIS OF VARIANCE FOR FACTORS AFFECTING WEANING WEIGHT FOR VARIANCE COMPONENT ESTIMATION FROM MODEL 1 WITHIN COMBINED SEXES OF CALVES

Source of variation	df	Mean Square	p value
Sire	99	20453.08	<.0001
Year of calf birth	14	24693.14	<.0001
linear	1	50706.12	.0001
quadratic	1	97981.43	.0000
cubic	1	4951.62	.2145
quartic	1	22.34	.9990
quintic	1	7964.76	.1163
residual	9	20453.08	<.0001
Sex of calf	1	229176.12	<.0001
Age of dam	9	23985.39	<.0001
linear	1	57856.35	<.0001
quadratic	1	144377.23	<.0001
cubic	1	946.39	.4329
quartic	1	7230.18	.0303
quintic	1	1430.55	.3349
residual	4	1006.97	.6232
Age of calf linear	1	84.03	.8152
quadratic	1	1131.99	.3910
cubic	1	2317.22	.2197
Remainder	1119	1536.79	

TABLE 38. ANALYSIS OF VARIANCE FOR FACTORS AFFECTING PREWEANING AVERAGE DAILY GAIN FOR VARIANCE COMPONENT ESTIMATION FROM MODEL 1 WITHIN MALE CALVES

Source of variation	df	Mean Square	p value
Sire	94	.048	<.0001
Year of calf birth	14	.284	<.0001
linear	1	.285	.0168
quadratic	1	.128	.1065
cubic	1	.039	.3705
quartic	1	.014	.5846
quintic	1	.450	.0029
residual	9	.340	<.0001
Age of dam	9	.235	<.0001
linear	1	.571	<.0001
quadratic	1	.311	<.0001
cubic	1	.001	.8467
quartic	1	.144	.0203
quintic	1	.000	.9990
residual	4	.022	.4976
Age of calf linear	1	.030	.2916
quadratic	1	.018	.4124
cubic	1	.008	.5926
Remainder	554	.027	

TABLE 39. ANALYSIS OF VARIANCE FOR FACTORS AFFECTING PREWEANING AVERAGE DAILY GAIN FOR VARIANCE COMPONENT ESTIMATION FROM MODEL 1 WITHIN FEMALE CALVES

Source of variation	df	Mean Square	p value
Sire	97	.027	<.0001
Year of calf birth	14	.243	<.0001
linear	1	.593	<.0001
quadratic	1	1.635	<.0001
cubic	1	.119	.0745
quartic	1	.089	.2213
quintic	1	.041	.0004
residual	9	.102	.0004
Age of dam	9	.103	<.0001
linear	1	.474	<.0001
quadratic	1	.365	<.0001
cubic	1	.004	.6887
quartic	1	.021	.3286
quintic	1	.005	.6414
residual	1	.014	.6321
Age of calf linear	1	.035	.2068
quadratic	1	.038	.1906
cubic	1	.043	.1664
Remainder	447	.022	

TABLE 40. ANALYSIS OF VARIANCE FOR FACTORS AFFECTING PREWEANING AVERAGE DAILY GAIN FOR VARIANCE COMPONENT ESTIMATION FROM MODEL 1 WITHIN COMBINED SEXES OF CALVES

Source of variation	df	Mean Square	p value
Sire	99	.366	<.0001
Year of calf birth	14	.412	<.0001
linear	1	.825	.0001
quadratic	1	1.296	<.0001
cubic	1	.159	.0749
quartic	1	.084	.1946
quintic	1	.100	.1573
residual	9	.366	<.0001
Sex of calf	1	3.438	<.0001
Age of dam	9	.379	<.0001
linear	1	.903	<.0001
quadratic	1	2.294	<.0001
cubic	1	.007	.5942
quartic	1	.138	.0215
quintic	1	.007	.5921
residual	4	.016	.6429
Age of calf linear	1	.035	.2491
quadratic	1	.022	.3540
cubic	1	.010	.5322
Remainder	1119	.026	

TABLE 41. ANALYSIS OF VARIANCE FOR FACTORS AFFECTING BIRTH WEIGHT BASED ON SIRE CONTRIBUTION FROM MIXED MODEL 27

Source of variation		df	Mean Square	p value
Within Sum Squares		650		
Total reduction		16	32048.89	<.0001
Mu		1	316619.99	<.0001
Sex of calf		1	407.95	<.0001
Year of sire birth		9	36.85	.0024
Age of dam		5	12.46	.4317
	linear	1	.00	.9990
	quadratic	1	33.13	.1078
	cubic	1	.76	.8072
	quartic	1	.15	.9131
	quintic	1	28.27	.1373
Remainder		634	12.77	

TABLE 42. ANALYSIS OF VARIANCE FOR FACTORS AFFECTING BIRTH WEIGHT BASED ON DAM CONTRIBUTION FROM MIXED MODEL 28

Source of variation	df	Mean Squares	p value
Within Sum Squares	650		
Total reduction	16	65195.23	<.0001
Mu	1	429481.15	<.0001
Sex of calf	1	429.91	<.0001
Year of dam birth	9	36.58	.0115
Age of dam	5	131.05	.0012
linear	1	7.89	.4230
quadratic	1	17.66	.2310
cubic	1	.00	.9990
quartic	1	26.29	.1441
quintic	1	12.29	.2605
Remainder	634	10.51	

TABLE 43. ANALYSIS OF VARIANCE FOR FACTOR AFFECTING WEANING WEIGHT BASED ON SIRE CONTRIBUTION FROM MIXED MODEL 28

Source of variation	df	Mean Square	p value
Within Sum Squares	650		
Total reduction	17	2030127.91	<.0001
Mu	1	562797.75	<.0001
Sex of calf	1	32789.28	<.0001
Year of sire birth	9	1893.04	.3982
Age of dam	5	2673.47	.1932
linear	1	8727.37	.0282
quadratic	1	157.65	.7675
cubic	1	4292.77	.1233
quartic	1	187.89	.7469
quintic	1	1.69	.9990
Age of calf	1	101.056	.8129
Remainder	633	1802.64	

TABLE 44. ANALYSIS OF VARIANCE FOR FACTORS AFFECTING WEANING WEIGHT BASED ON DAM CONTRIBUTION FROM MIXED MODEL 28

Source of variation		df	Mean Square	p value
Within Sum Square		650		
Total reduction		17	4400264.62	<.0001
Mu		1	685978.77	<.0001
Sex of calf		1	34014.95	<.0001
Year of dam birth		9	6542.02	.0001
Age of dam		5	5977.34	.0045
	linear	1	20857.01	.0006
	quadratic	1	2138.73	.2675
	cubic	1	6814.30	.0481
	quartic	1	70.97	.8399
	quintic	1	5.69	.9990
Age of calf		1	1405.15	.3687
Remainder		633	1736.44	

TABLE 45. ANALYSIS OF VARIANCE FOR FACTORS AFFECTING PREWEANING AVERAGE DAILY GAIN BASED ON SIRE CONTRIBUTION FROM MIXED MODEL 27

Source of variation	df	Mean Square	p value
Within Sum Square	650		
Total reduction	17	11.110	<.0001
Mu	1	3.684	<.0001
Sex of calf	1	.389	<.0001
Year of sire birth	9	.032	<.0001
Age of dam	5	.050	<.0001
linear	1	.188	<.0001
quadratic	1	.037	.0127
cubic	1	.001	.7389
quartic	1	.025	.0402
quintic	1	.001	.6692
Age of calf	1	.014	.1248
Remainder	633	.006	

TABLE 46. ANALYSIS OF VARIANCE FOR FACTORS AFFECTING PREWEANING AVERAGE DAILY GAIN BASED ON DAM CONTRIBUTION FROM MIXED MODEL 28

Source of variation	df	Mean Square	p value
Within Sum Squares	650		
Total reduction	17	24.264	<.0001
Mu	1	4.140	<.0001
Sex of calf	1	.383	<.0001
Year of dam birth	9	.064	<.0001
Age of dam	5	.139	<.0001
linear	1	.595	<.0001
quardratic	1	.060	.0013
cubic	1	.001	.8435
quartic	1	.038	.0106
quintic	1	.001	.7737
Age of calf	1	.020	.0592
Remainder	633	.006	

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BIOGRAPHICAL SKETCH

Sornthep Tumwasorn was born July 25, 1951, to Captain Sombat and Tongluen Tumwasorn. He is a native of Thailand. Sornthep is married to Somying and has two sons, Pattarawuth and Nattapol.

In 1970, he received his high school diploma with honors from Sentinel High School, Missoula, Montana under the American Field Service Scholarship. While in Montana he lived with Mr. and Mrs. Delaney and their family. Upon his return to Thailand in 1971, he received his diploma from Nakhon Sawan Comprehensive School and in 1975 he received B.Sc. in Agriculture, majoring in Animal Science, from Kasetsart University. In 1975, he received a University Development Scholarship (U.D.C.), a competitive scholarship from the University Bureau of Thailand.

Sornthep received his M.S. in Genetics from Kasetsart University in 1977 and worked as research assistant for the Rockefeller Foundation with a joint appointment in the Animal Science Department of Kasetsart University with research specialization in buffalo and cattle breeding and genetics. During the initial year of his career, he developed the quarterly publication, the Buffalo Bulletin, which is now being distributed to scientists in more than 44 countries. During the first 5 years of his career as an instructor at the Department of Animal Science, Kasetsart University, Bangkok, Thailand (1977-1981), he published more than 30 scientific papers, 60 extension articles, 2 text books, and 7 proceedings papers at international and national seminars relating to buffalo and cattle breeding and production in developing countries. In August 1982, Sornthep entered the Graduate School of the University of Florida to pursue a Doctor of Philosophy degree in animal science emphasizing animal breeding and genetics. His Ph.D. program has been supported by a Rockefeller Foundation Scholarship.

He is a member of the Animal Husbandry Association of Thailand, Thai Society of Agricultural Science, American Society of Animal Science, and the Gamma Sigma Delta Honor Society of Agriculture.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Timothy A Olson

Timothy A. Olson, Chairman
Associate Professor of Animal Science

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Don D. Hargrove

Don D. Hargrove
Professor of Animal Science

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Alvin C Warnick

Alvin C. Warnick
Professor of Animal Science

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Michael A.

Michael A. DeLorenzo
Assistant Professor of Dairy Science

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Glen H Smerage

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Associate Professor of Agricultural
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This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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